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REPORT ON THE PHOSPHATE ROCKS OF CENTRAL KENTUCKY

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THE CENTRAL KENTUCKY PHOSPHATE FIELD

By

W. C. Phalen.

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Scale: 1 inch=10 miles.

THE CENTRAL KENTUCKY PHOSPHATE FIELD

By W. C. PHALEN.

INTRODUCTION.

The object of this report is mainly to present to the public, unfamiliar with Kentucky's resources, data and information of general interest bearing on the phosphate deposits of the State. In it are described the location and geographic distribution, the extent, and relative importance of the deposits under present conditions of the phosphate and fertilizer industry, and what may be expected of them as time goes on and new processes for working them are developed. The methods of mining and preparing brown rock phosphate for market as practiced in the neighboring state of Tennessee are also briefly outlined, for without doubt Tennessee practice and experience will be utilized when the Kentucky deposits come to be more generally worked.

The element phosphorus is one of the three essentials of the commercial fertilizers of the present day. It is supplied to plants in the form of acid phosphate, raw ground rock phosphate, basic slag, and various bone products, such as steamed bone meal, raw bone meal, bone ash, and bone black. Of these various substances acid phosphate is the most largely used. It forms one of the principal ingredients of nearly all commercial fertilizers. It is prepared from the naturally occurring phosphate rock and the essential ingredient in this rock is calcium phosphate which is also often referred to as bone phosphate of lime or bone phosphate, or simply abbreviated to "BPL". Any or all of these terms, which mean the same thing, will be used in this report.

Any extensive deposit of phosphate rock in the United States is either of present or prospective importance. Those in central Kentucky, though not yet worked to any marked extent, occupy a wide territory, are of intermediate grade, and therefore constitute a reserve

supply of inportance. They were investigated by the writer in 1914 and 1915 and the following descriptions summarize the results obtained.

This report is primarily an economic report and the geologic features are only considered in the light that they threw on the economic problems involved.

FIELD WORK.

The field work on which this report is based was done in September and October, 1914, and in June, 1915. It extended over the better known phosphate area lying between the towns of Versailles and Midway, Woodford County, especially in the vicinity of Wallace. Considerable work was also done west and northwest of Midway, between the Louisville and Nashville Railroad and South Elkhorn Creek. Studies were also made in the vicinity of the Forks of Elkhorn Creek, Franklin County, in and around Lexington, Fayette County, and in a few isolated localities which will be mentioned in the subsequent descriptions.

The writer gladly acknowledges the efficient help rendered him by Mr. P. B. Winn, of Lexington and Winchester, Kentucky, in the field work, and also the many valuable suggestions made by Professor A. M. Miller, of the State University at Lexington. References to the work of Miller will be made at the appropriate places in the text.

During the course of this work nearly two hundred shallow drillings were made, the cores carefully sampled, and analyses of the samples together with others were made in the laboratories of the United States Geological Survey by W. C. Wheeler and R. M. Kamm.

GEOGRAPHY AND TOPOGRAPHY.

The greater part of the territory discussed in connection with the Kentucky phosphate field occurs in the Georgetown quadrangle. This quadrangle comprises a large part of Fayette, Woodford and Scott, and small parts of Franklin and Jessamine counties. Studies were also made in parts of Franklin County off the northwest corner of the Georgetown quadrangle and in the vicinity of Pine Grove Station, Clark County. The phosphate areas within the Georgetown quadrangle in Franklin

County have been studied by A. M. Miller* and descriptions of the phosphate areas themselves have been prepared by A. E. Foerste.† The writer acknowledges the help received from the reports of these geologists and due credit is given to them in the proper places in these descriptions.

The low broad hills and the rolling topography are characteristic of this beautiful country, which is of the type known to geologists as a peneplain. The important phosphate deposits occur at the surface of this old peneplained area, that is, an area which has long been exposed to erosion and which has been worn down to an approximately level surface with most of the broad level hill tops now between 900 and 1,000 feet above sea.

The rocks in this section containing the phosphate are entirely limestones. The exposure to weathering of a soluble rock, such as limestone is under ordinary conditions, has here brought about fundamental changes in which have been involved the removal of a large part of the country rock. The removal of this rock has been accomplished both by chemical and mechanical means. Limestone as it usually occurs is mixed with more or less of insoluble hydrous silicates of aluminum (clay). The limestones in this region contain also the insoluble phosphate rock. The limestone has been removed, probably largely in the form of the soluble bicarbonate $Ca\ H_2(CO_3)_2$ and the clay left after the solution of the $Ca\ CO_3$ has been carried off, in part at least, mechanically. There is scarcely any doubt that some phosphate rock has been carried off in this manner and thus wasted for all time.

In recent times the rate of removal of the residual material, clay and phosphate rock, has been slower than its accumulation, and in some places as revealed in natural exposures and drillings, it is 10 or more feet thick. In many other places, of course, the basal limestone outcrops.

The principal streams within the areas under discussion are North and South Elkhorn Creeks and their tributary branches. Fortunately South Elkhorn Creek is not too remote to be considered as a possible source of

*Miller, Arthur M., Geology of the Georgetown quadrangle; Kentucky Geological Survey, Series 4, Vol. 1, Pt. 1, 1913, pp. 317-364. Geology of Franklin County; Ky. Geol. Survey, Series 4, Vol. 2, Pt. 3, 1914, pp. 11-87.

†Foerste, A. E. The phosphate deposits in the upper Trenton limestones of Central Kentucky; Ky. Geol. Survey, Series 4, Vol. 1, Pt. 1, 1913, pp. 391-439.

wash water, great quantities of which are needed in phosphate mills for washing purposes. In a limestone region where sinks abound and where much of the drainage is below ground, the presence of a stream like South Elkhorn Creek may prove to be of the greatest economic importance to an industry requiring a very cheap and abundant water supply. The topographic and geologic map shows the great paucity of important streams except South Elkhorn Creek in the neighborhood of the phosphate deposits.

The meandering character of the Elkhorn Creeks is pronounced. The presence of streams would be hardly suspected when the country is viewed from a hilltop. Only the dense growth along them indicates their courses. There seems little doubt that the irregular stream courses have been inherited or retained from a period in their history when they flowed over a low broad plain. As the region has been elevated they have cut down or deepened their channels, but this has taken place with few exceptions along their original courses. Such streams are said to have intrenched themselves, and their meanders are known as intrenched meanders.

GEOLOGY.

Stratigraphy.

The following notes on general stratigraphy and structure of the quadrangle are compiled largely from the reports of Prof. A. M. Miller, as the writer spent less than three months in the area, working chiefly on the economic problems of the phosphate beds alone.

The country rocks associated with the phosphate rock deposits are all limestones of different lithology and degrees of purity. The chief foreign ingredients in them are clay, chert, and the phosphate rock itself. They are all of marine origin and belong to the middle part of the Ordovician system; their total thickness is approximately 330 feet.

The best stratigraphic section in the vicinity of the area which the writer knows of is on the hill road at the Old Crow Distillery near the mouth of Glenn's Creek. The locality is about 5 or 6 miles west of the west boundary of the quadrangle. The following illustration (Figure 1)

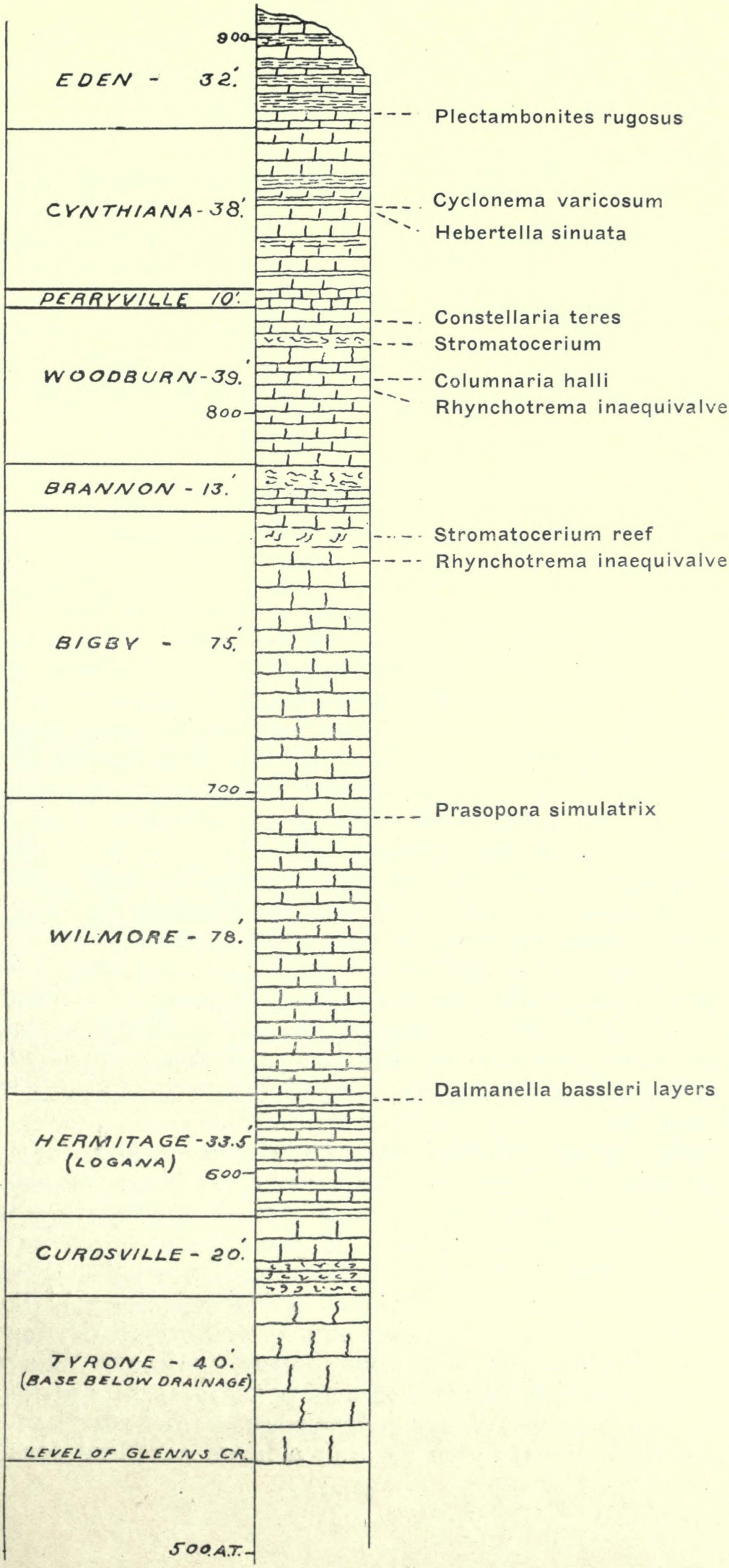

Fig. 1.

Geological section exposed at the Old Crow Distillery from level of Glenn's Creek to top of hill on North Side of the creek, taken along steep road intersecting the pike at the distillery. (After A. M. Miller.) Ky. Geol. Survey, Series IV, Vol. 1, Part 1, 1913.

represents the section at this locality as given by Professor Miller.

The phosphate deposits of the Georgetown quadrangle occur chiefly in the beds to which the name Woodburn is applied in the section quoted in Fig. 1. These beds, together with the underlying Brannon bed of Miller, correspond to the Flanagan chert of M. R. Campbell in the Richmond folio of the United States Geological Survey.

DESCRIPTION OF FORMATIONS.

"Wilmore" and Bigby (?) Limestones.

The rocks of this area to which the names Wilmore and Bigby have been applied by Professor Miller consist of thin-bedded limestones with some shale between the layers. There is no distinct lithologic or stratigraphic break between them. The name Wilmore is preoccupied by the Wilmore sandstone member of the Conemaugh formation, and it is therefore quoted in this report. The rocks called Bigby by Professor Miller are correlated by him with the Bigby limestone of southwestern Tennessee. As this correlation is not established the name Bigby (?) limestone is used in this report. The total thickness of these formations within the Georgetown quadrangle is about 90 feet. Of this total thickness 65 to 75 feet belong to the Bigby (?) limestone and the rest, namely 15 to 25 feet, belong to the "Wilmore." According to Miller the "Wilmore" is characterized by the brachiopod *Dalmanella bassleri* and the "chocolate drop" or hemispherically shaped bryozoan *Prasopora simulatrix*.

The Bigby (?) formation contains more abundantly than any other formation the brachiopod *Rhynchotrema inaequivalve. Hebertella frankfortensis,* another brachiopod, is also abundant in the Bigby (?) and upper part of the "Wilmore," reaching its culmination lower down in the section than *Rhynchotrema inaequivalve.* At the top of the Bigby (?), and confined to a vertical range of not over 10 feet, is a very characteristic assemblage of fossils comprising two brachiopods, *Dinorthis ulrichi* and *Strophomena vicina,* a bryozoan of globular habit, *Cyphotrypa frankfortensis,* and a large coralline fossil

Stromatocerium pustulosum, together with other bryozoa.

"The coralline fossil *Stromatocerium putulosum* is usually so abundant at this horizon as to indicate that it formed a reef in this region in the ancient Ordovician sea." It is especially abundant in the northern part of the Georgetown quadrangle and as far south as the latitude of Midway. In places it is as much as 6 feet in thickness and as its top is practically at the base of the next overlying formation (the Flanagan), it has an economic, as well as stratigraphic significance, for the reason that all important phosphate deposits are likely to be found either close above or close below it. According to Foerste phosphate rock also occurs locally in the upper part of the Bigby (?) limestone.

Flanagan Limestone.

The term Flanagan chert was given by M. R. Campbell in the Richmond Folio of the United States Geological Survey to the next overlying formation. The term was applied to the rocks occupying the interval between the Lexington and Winchester limestones, the latter terms being practically the same as Linney's Trenton and Hudson formations as used in the latter's reports on the counties in the blue grass region for the Shaler and Procter Kentucky State Surveys.

According to Miller* only the lower 13 to 15 feet of the Flanagan consists of siliceous limestone which forms chert on weathering. The cherty character is not at all conspicuous excepting as the result of ordinary atmospheric weathering processes where the beds are at the surface. The remainder of the Flanagan consists of 30 to 40 feet of thin-bedded, granular, phosphatic limestone. The lower cherty beds are herein called Brannon cherty member, and the upper or phosphatic beds are called Woodburn phosphatic member.

Brannon Cherty Member.—The beds to which Miller has applied the name Brannon in his description of the rocks of the Georgetown quadrangle consist of 13 to 15 feet of siliceous limestone which forms chert on weathering. The beds are named for exposures at

*Miller, A. M., Geology of the Georgetown quadrangle; Ky. Geol. Survey, Series IV., Vol. 1, Pt. 1, 1913, p. 324.

Brannon Station, on the Queen and Crescent Railroad, a short distance south of the southern boundary of the Georgetown quadrangle. These rocks are regarded by Miller, Foerste and Ulrich, as representing the lower or cherty part of Campbell's Flanagan chert.

It is the upper part of the Brannon, with its highly contorted or bouldery layers (see Pl. 1 and 2) that is so characteristic and it is this portion which furnishes most of the chert at its weathered outcrop. When freshly exposed the Brannon is very firm and hard and requires blasting to remove it. It is a good water bearer and consequently its outcrop is generally marked by the presence of springs. The Big Spring at Versailles is at this horizon and also what are known as the Maxwell or Sinking Springs at Lexington. The Big Spring at Spring Station is also near this horizon. It is pre-eminently the formation occurring in the numerous sinks found in this quadrangle. This latter association may be due to its tendency to resist temporarily destruction by solution and to form, therefore, the roofs of caverns. Later, when brought to the surface by denudation, it goes to pieces rapidly, is decomposed into chert and the roof of the cavern falls and a sink results. There are instances where the collapse of a cavern roof has taken place suddenly and has entrapped grazing stock.

As may be inferred from the behavior of this limestone under conditions of weathering, natural exposures of the firmer layers are rare. The best exposures are along railroad cuts and in other artificial excavations and in sinks of rather recent development. The Brannon is splendidly exposed in a cut on the Cincinnati, New Orleans and Texas Pacific Railroad (Queen and Crescent route) in Lexington near the Virginia Avenue (Lottie Street) bridge. It is usually a spring horizon and the water comes out directly above the contorted limestone layer which is from 1 to 1½ feet thick at this locality. The cherty phosphatic layer shows above the contorted layer, but very little of it is in massive form. (See plate 1.)

Near where the photograph was taken the phosphatic layer is 8 to 10 feet thick, but owing to the presence of considerable wash the exact thickness is not readily ascertained.

The Brannon resembles a sandy limestone at this locality and thin bands of blue shale up to 2 feet in thickness were observed. It is very irregularly bedded—a condition especially noticeable where the base of the upper or contorted layer rests on that containing the blue-drab shale. This contact is so irregular that nonconformity or even faulting is suggested. In addition to this locality, eight other localities where the Brannon outcrops are listed by Miller.

The Brannon is of interest because in most instances it forms the base of the richest phosphate deposits of this region.

WOODBURN PHOSPHATIC MEMBER.—The strata to which the name Woodburn has been applied by Miller are described by him as consisting of "about 30 to 40 feet of thin bedded, granular, phosphatic limestone. The name comes from the celebrated Alexander estate, in Woodford County, where the beds are said to be very typically developed, especially as regards their most distinctive feature, the possession of phosphate. The most conspicuous fossil in this formation is the coral, *Columnaria halli.* It is commonly found in a silicified condition weathered out from its matrix and found loose in the deep, dark red soil formed from the decay of the limestone at its horizon. Another very common fossil in this formation is the very small gastropod *Cyclora minuta.* This fossil occurs only as phosphatic casts of the inside of the shell, and its presence in association with the more phosphatic phases of the rock suggests strongly that the animal which formerly inhabited the shell played an important part in the original segregation of the phosphate of lime from the sea water." According to Miller, Foerste and Ulrich, the Woodburn is equivalent to the upper and major part of the Flanagan chert of Campbell.

At the old workings of the Central Kentucky Phosphate Company at Wallace, a good opportunity is presented to study the stratigraphic position of the phosphate rock deposits themselves. From the data which Foerste* obtained he concluded that "the diggings so far made by the Phosphate Company, at their

*Foerste, A. E. The phosphate deposits in the upper Trenton limestone of Central Kentucky; Ky. Geol. Survey, Series IV., Vol. I., Pt. I., 1913, pp. 412-413.

plant southeast of Wallace, belong to the upper part of the Benson or Bigby bed, and not to the Woodburn bed. This is confirmed by the latest diggings made at the plant. Here the basal part of the Brannon bed was exposed about half way up the hill slope, above the level of the first three strips of phosphate rock, 50 feet wide, so far removed. Here *Dinorthis ulrichi* and *Stromatocerium* occurred in the upper part of the phosphate rock, beneath the base of the Brannon layer, clearly indicating the geological horizon. The phosphate rock struck northeast of the house on the Steele farm, about a mile and a quarter east of Wallace Station, however, belongs to the upper part of the Woodburn horizon.

"It is evident that, locally, weathering away of the Woodburn bed has resulted in the concentration of phosphatic material at the top of the next underlying limestone, which in this case is the Benson or Bigby bed. It is interesting that, at the only locality at which so far any actual commercial development of the phosphate field has been undertaken, the only workable rock so far exploited should belong to the Benson and not to the Woodburn horizon. Aside from this limited area in the neighborhood of Wallace, there are also other localities at which phosphate rock occurs in the upper part of the Benson bed, but by far the greater part of occurrences of phosphate deposits, taking the field as a whole, occur in the Woodburn bed, and this is especially true when the unweathered rock is taken into account. This suggests the origin of the most of the phosphatic deposits in central Kentucky in the Woodburn horizons, although locally concentration may have extended downward into the upper part of the Bigby.

"The occurrence of *Strophomena vicina* in the phosphatic layers in the upper part of the Stark quarry, a mile and a half south of Wallace, suggests that these layers also belong to the upper part of the Benson section."

The phosphatic rock deposits are proved, therefore, to extend through a considerable stratigraphic interval. It is clear from the descriptions that the phosphate bearing beds cannot be represented on the map by a single line, and not very readily by a band as in ordinary geologic mapping.

The Woodburn abounds in sinks.

Rocks Overlying the Flanagan Limestone.

Only the lower member of the formation overlying the Flanagan is of interest or importance in this report for the reason that it occurs close above the phosphate rock horizon and thus may prove of great assistance in helping to locate it. This member is a gastropod horizon. In western Woodford and adjacent parts of Franklin County the shells of gastropods are massed together in a ledge of cherty limestone about 5 or 6 feet thick. In its massive condition this limestone is found in the western and southwestern parts of the Georgetown quadrangle south of South Elkhorn Creek. Its former presence in the southwestern quarter of the area—that is in the region south and west of South Elkhorn Creek—may be readily traced by means of its outliers and the abundance of gastropod chert debris found in the soil. The latter on account of its resistant character may even be found over areas from which the formation has long been removed by weathering, if it ever existed in these parts. Where it occurs as a distinct horizon the phosphate rock bed should be looked for below it on the hills.

STRUCTURE.

The area of the phosphate deposits is on the western flank of the Cincinnati geanticline—a broad, low dome toward the center of which the rocks outcropping become lower and lower in the geological time scale. The rocks in this region, therefore, dip from west to northwest at very low angles—so low that the dips cannot be determined instrumentally, that is with a clinometer, but must be reckoned over broad areas on the basis of actual elevations on particular beds. The average rate of this dip is about ten feet per mile and the main streams fall at approximately the same rate in the same direction, thus running over approximate dip slopes. It follows, therefore, that the highest lands are found in the southeast part of the region and the lowest in the northwest. The relief in the Georgetown quadrangle is about 350 feet, the difference between 1050 feet along the Nicholasville pike in the southeastern part of the Georgetown quadrangle, and 700 feet, the approximate elevation of South Elkhorn Creek where it leaves the quadrangle.

The uniformity of dip to the northwest has been interfered with in places by disturbances which have resulted in faults. Most of these are of slight vertical throw and of limited extent in surface outcrop. They are "tension or normal" faults and have a wide drag zone, for which reason the stratigraphic throw is great compared with the vertical. Most of those located occur in pairs, one of which may be considered the primary and the other the secondary or compensating fault. An illustration of other minor movements in the rocks is shown in Plate III. The faults so far as known do not involve those areas where the important phosphate deposits are found.

DISCOVERY OF THE FIELD.

There seems to be no question but that the distinction of having called attention to phosphate in the limestones of central Kentucky belongs to Dr. Robert Peter, Chemist of the Kentucky Geological Survey, under the administration of N. S. Shaler. This was done as early as April, 1849, in the Albany Cultivator of New York.* It was Dr. Peter also who first pointed out the association of phosphate and cyclora and the dependence of the soils of the blue grass region for their fertility on the presence of phosphate rock.

In the report by Dr. Peter to State Geologist Shaler, dated February, 1877, there is given the analysis (No. 1778) of a phosphatic limestone from McMeekin's quarry (see Plate IV.) on the Newtown pike, 3 miles north of Lexington. The specimens were collected by Dr. Peter himself and the phosphate layer was reported by the quarryman to be as much as 1 foot thick. The rock is described as being somewhat friable, of a bluish gray color, but brownish gray on the weathered surfaces, as containing many microscopic marine univalve shells and as adhering strongly to the tongue. The phosphates in this limestone were found to contain as much as 31.815 per cent. of the weight of the rock of phosphoric acid, which is equivalent to 69.452 per cent. calcium phosphate.

*Ky. Geol. Survey, Chemical Analyses A, Part I., 1890, p. 246. Ky. Geol. Survey, Chemical Analyses A, 1877, pp. 65-66. Also described as Vol. 4, new series, Reports Geol. Survey of Ky., pp. 65-66.

The composition of the sample was as follows:

Analysis of the Fayette County Phosphate Rock, Dried at 212° F.

Phosphoric acid, lime, magnesia, alumina, and iron oxide	85.270
Calcium fluoride	not est
Carbonate of lime	9.180
Carbonate of magnesia	.371
Silica and insoluble silicates	4.780
Alkalies, organic matter, etc., not estimated	3.99
	100.00

In his observations on this rock, Dr. Peter makes the significant statement "the subject is worthy of further investigation, especially in view of the agricultural and commercial value of the phosphate for use as fertilizers. As is well known, the abundant phosphates of the rock substratum is one of the main causes of the great and durable fertility of our blue grass soil so-called, as well as of the superior development of the animals reared and nourished on its products."

At the time the specimen of phosphatic limestone whose analysis is given above was collected, the quarry was not in use and the statement that the layer of rich phosphatic rock was as much as a foot thick could not be verified. When the quarry was again opened and worked for turnpike material in 1877, a more complete examination was made by Dr. Peter with the following results:

Phosphatic Limestone From the McMeekin Quarry, Northwest Side of Newtown Turpike, 3 Miles North of Lexington, Taken From Irregular Layers About 1 Foot in Thickness.

Composition Dried at 212° F.

Lime carbonate	49.160
Magnesia carbonate	.090
Phosphates, with $Al_2O_3Fe_2O_3$, etc. (containing 21.018 per cent. phosphoric acid)	46.540
Siliceous residue	2.820
Organic matter and loss	1.390
	100.000

The analyses given above and others indicated an irregular distribution of phosphate, and so 11 other samples were selected from portions of the phosphatic layer. The quantity of phosphoric acid (P_2O_5) in these 11 samples varied from 5.053 per cent. to 21.940 per cent., and averaged 15.896 per cent., pointing to an irregular distribution and an irregular local origin.

Interest in the occurrence of phosphate rock and phosphatic limestone in Kentucky did not develop at once, or at least lead to further field exploration or investigation. The discovery and the commencement of work in the Tennessee phosphate field in 1894-1895 quickened interest in phosphate rock deposits in general. The association of calcium phosphate layers at the top of the so-called Trenton limestone near Lexington with certain organic remains was pointed out by A. M. Miller as early as February, 1896.* During the summer of 1904, Miller was engaged in field work for reports on the geology of Jessamine, Woodford and Franklin counties. These reports, except that for Franklin County, were never published, but in that on Woodford County he referred to the phosphate deposits and their exceptional richness at the top of the so-called Trenton in the territory between Midway and Versailles.

In a report by the former director of the Kentucky Geological Survey, Charles J. Norwood,† it is stated that "Professor Miller discovered the exact representative of the rock phosphate beds of Mt. Pleasant, Tennessee, some examples running as high as 72 per cent. phosphate, and having definitely differentiated them, he was able to trace them over considerable areas." Thus the fundamental studies made by Professor Miller entitle him to the credit of suggesting the possibilities of this region as the site of potentially important phosphate rock deposits.‡

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*Miller, A. M. The association of the gastropod genus cyclora with phosphate of lime deposits. Am. Geol., Vol. XVII., 1896, pp. 74-76.

†Ky. Geol. Survey Rept. on the progress of the survey for the years 1904-1905, pp. 25-26.

‡It has been stated that in the summer of 1915, a negro while digging post holes on the farm of H. L. Martin, near Midway, discovered what he considered phosphate rock, similar to the brown phosphate rock in Tennessee. Mr. Martin verified the negro's opinion. See Gardner, James H., Mines and Minerals, November, 1912, p. 207; Waggaman, W. H., U. S. Dept. of Agriculture, Bureau of Soils, Bull. No. 81, March 20, 1912, p. 24.

THE PHOSPHATE ROCK.

TYPE OF ROCK.

Phosphate rock occurs in a variety of ways and has been designated by a variety of names in the different states where found. The Ordovician phosphate rock of central Kentucky belongs entirely in a class known as brown phosphate rock, first so-called in middle Tennessee. It occurs as a distinctly laminated residual deposit, also as filling solution cavities or pockets in a more or less phosphatic limestone. (See Plates V. and VI. and Figure 4.)

The rock itself occurs in porous or loosely coherent plates and where exposed, naturally or artificially, these plates vary in thickness from the very thinnest up to those a few inches thick. The more massive rock is referred to as lump, plate, or hard rock. The latter may also occur in thick heavy slabs of several inches, or even a foot or more in thickness. This massive type is not common in Kentucky. It was observed in a natural exposure on the Louisville Southern Railway near the Cahill place, about a mile and a half west of Lexington and on the Harkness estate (Walnut Hall) east of Cane Run and near the Fayette-Scott county line in the northeast part of the Georgetown quadrangle. Doubtless it is found in many other places that were not seen.

Usually the plates or slabs are separated from each other by layers of loosely cemented or porous material consisting of phosphate rock in a fine state of division mixed with more or less clay. The explanation of this form of rock will be made clear under descriptions of origin. The material is termed phosphate muck and is found between individual plates, especially in fresh exposures or drill holes. Muck, or the soft mixture of phosphate and clay, often is found just above the limestone on which the phosphate rock stratum rests.

There is also another form of brown rock known as phosphate sand, some of which is very rich in calcium phosphate and is therefore of commercial value. Mixtures containing varying proportions of plate rock, sand rock, and muck constitute what is included under the term brown phosphate rock.

The color of the rock varies from a drab through a grayish and yellowish brown to a deep brown or almost

black. The muck layers so often found overlying the limestone at the bottom of the numerous holes drilled by the writer, are usually nearly black, and in some cases it was thought that the dark color might be due to the presence of hydrous oxides of manganese which are a very common constituent of the soils in the blue grass region. The thickness of the beds will be described under mode of occurrence.

MODE OF OCCURRENCE.

Brown rock phosphate deposits depending on their manner of occurrence, have been designated as "blanket" and "collar" deposits.* The latter have also been called

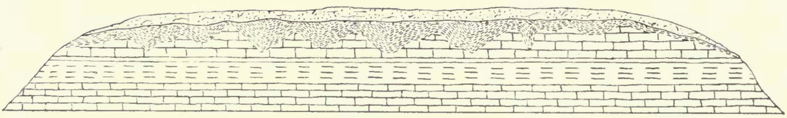

Fig. 2.
Blanket phosphate deposit on low, flat hill. Showing the development of "horses" and "cutters."

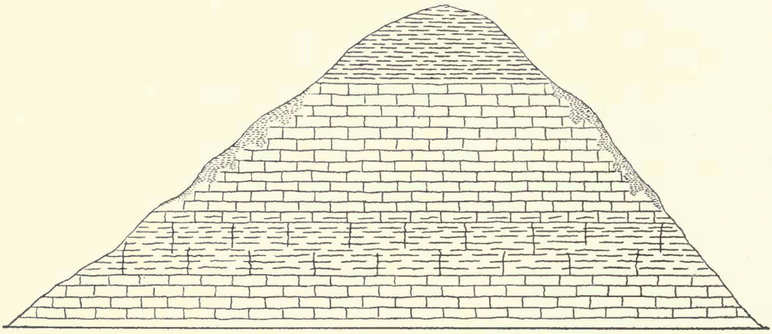

Fig. 3.
"Collar" or "run" phosphate deposits formed on steep hillside.

"hat band" or "rim" deposits. The name suggests the character of the formation. The term "blanket" applies to the nearly horizontal deposits of considerable areal extent, while those designated "hat band" or "rim" occur within a limited vertical zone on the hillsides. (See Figures 2 and 3.) The character of the deposits depends

*Hayes, C. W., U. S. Geol. Survey, Folio No. 95, 1903, pp. 5-6.

on the topography or lay of the land; and it is obvious that the blanket deposits are the most extensive, and with other conditions the same, are the most valuable. It is also obvious that there cannot be any sharp or arbitrary division between blanket and collar deposits, but that the one type may merge imperceptibly into the other.

At the old workings of the Central Kentucky Phosphate Company, the predecessor of the United Phosphate & Chemical Company, near Wallace, there are good illustrations of the collar type merging into the blanket type of deposit. The workings here are not very extensive, at least not enough to indicate to one who has not prospected the area, whether the deposits cover the entire hill where work has been done and hence belong strictly to the blanket type. The drilling done in the course of this investigation, and the information gathered from talking with land owners who are acquainted with conditions from local drilling, seems to indicate that the deposits belong to both the collar and blanket types, and that the former are probably the more numerous.

It was stated above that the type of the deposits depends on the topography. The topography in this part of Kentucky is gently undulating, or rolling. A study of it shows clearly that it has resulted from the dissection, or cutting down of a gently sloping surface which originally was more than 1050 feet high in the southeastern part of the Georgetown quadrangle, and more than 850 or 900 feet high in the northwestern corner. Such topography affords the best conditions for the formation of residual phosphate deposits, providing the other requisite conditions are fufilled. The Lockport quadrangle to the northwest furnishes an example where geological conditions are similar to those in the Georgetown quadrangle, but where the topography is such as to preclude the possibility of the formation of phosphate rock deposits owing to its rugged character, except at the very outcrop. It follows, therefore, that the economic importance of such deposits should be slight.

The phosphate rock deposits are always associated with limestone and it is from a phosphate bearing limestone that they are considered to be derived. The original phosphatic material occurs in definite bands in the

limestone mixed with calcium carbonate. (See Plate VII.) It is believed without much doubt that these highly phosphatic bands are original, and that they were laid down alternately with bands of limestone containing less phosphate, or none at all.

With the leaching of the limestone the insoluble phosphate rock and the other insoluble materials originally present, which are chiefly clay, silicified fossils, and chert debris, have slumped down slowly onto the underlying limestone. The capping of clay has resulted from the similar changes which have taken place in higher clay bearing or argillaceous limestone beds. In the writer's opinion no other theory or hypothesis is required to explain the formation of the phosphate deposits. Solution has taken place along joint planes more rapidly than in the other places and has led to the formation of so-called "cutters" or "horses." (Plate IX.) Horses are the limestone masses projecting into the phosphate rock layers, the latter of which curve over them in arches, as will be observed from the illustrations (Plates V. and X.) and in the cutters between the horses the phosphate rock deposits often show abnormal thickness from the mechanical slumping down from the flanks of the horses. (Figure 4.) This behavior of the phosphate rock leads to great variations in the thickness of the deposits and necessitates most thorough prospecting before the average thickness over a given area can be closely estimated. Splendid examples of the irregular limestone surface underlying the phosphate rock are to be seen at the old workings near Wallace (Plate IX.), and in sections at many quarries in the region, among which may be mentioned the Haggin quarry at Elmendorf, east of Maysville pike; the Stark quarry on the Versailles-Midway pike; the James P. Headley quarry just outside of Lexington city limits and east of the Russel Cave pike, and doubtless at many other quarries over the entire region.

Actual exposures of limestone and overlying phosphate are not very common. The mode of occurrence, therefore, cannot be studied as closely as desirable from the commercial point of view from either outcroppings or quarries. Drilling operations and the digging of pits are necessary to throw the maximum light on the mode

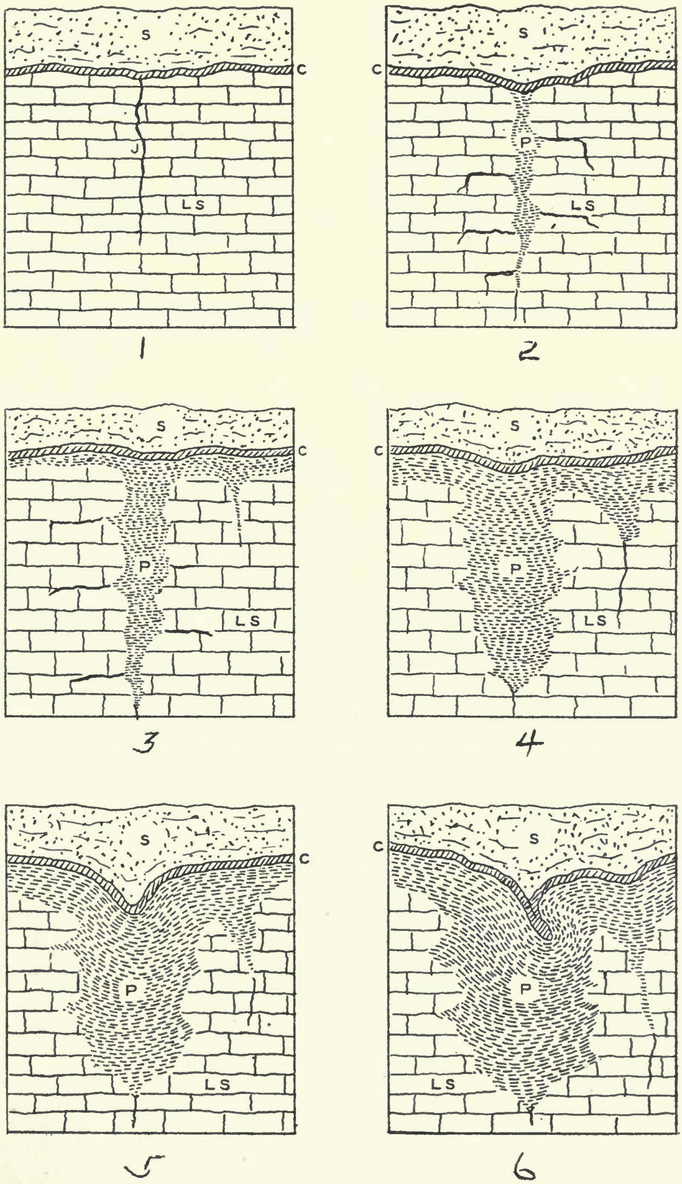

Fig. 4.

C—Clay seam. S—Soil. L.S.—Limestone. J—Jointing. P—Phosphate.

DEVELOPMENT OF CUTTERS.

Scale—1 inch=20 feet approximately.

Showing the development of cutters after J. S. Hook,

"The Resources of Tennessee."

Vol. IV, No. 2. April, 1914. P. 64.

of occurrence. The former method of prospecting will be described under the proper heading.

The overburden of the phosphate rock consists, as has been stated, chiefly of clay mixed with different materials like chert debris, silicified fossil remains, etc. This overlying soil contains small quantities of lime phosphate. The following section was measured on the Louisville Southern Railway near the Cahill place already referred to as about 1½ miles northwest of Lexington:

Section of Phosphate Rock on the Louisville Southern Railway Near the Cahill Place, 1½ to 2 Miles Northwest of Lexington.

4′		Overburden.
3′	6″	Massive phosphate rock.
3′	9″	Clay.
3′	6″	Limestone and blue shale.

A sample of the overburden gave less than 2 per cent. phosphoric acid. A sample of overburden from station No. 11, near Hulett's, gave less than 1 per cent. phosphoric acid. A sample collected from a thickness of 3½ feet in excavating for a telephone pole at the roadside ¾ of a mile northwest of Hillenmeyer Station, gave less than 2 per cent. phosphoric acid. Though the overburden contains but little phosphate, its possibilities as a filler in making commercial fertilizer ought not to be lost sight of, for it is this soil that renders the blue grass region so productive.

The abundance of iron and manganese oxide concretions in the soil overlying the phosphate rock is worth remarking. A notable quantity of these concretions occurs near Station No. 11, or Hulett's, on the interurban trolley line between Lexington and Nicholasville. Here a layer of the concretions 3 feet thick was observed. The top soil in the entire blue grass region is shot through with manganese concretions, usually of small size. These, no doubt, were originally disseminated in the limestone and have been segregated during the process of weathering.

The presence of manganese is of interest since it has been considered to have some fertilizer value. An elaborate series of experiments has been carried on by the Bureau of Soils, U. S. Department of Agriculture,

having in view the determination of the effect of manganese salts on grain and vegetable growth. Both pot and field tests were made and the conclusion was reached that crop growth in unproductive sandy loam was stimulated by the addition of 5 to 50 parts of manganese to a million of soil, whereas no effects were noticeable when a productive loam soil was used. In some tests an actual decrease in yield was attributed to the addition of manganese salts.*

DISTRIBUTION AND CHARACTER OF THE PHOSPHATE BEDS.

A somewhat restricted district in the vicinity of Wallace a few miles south, southeast, and southwest of Midway, Woodford County, is the only one of prominence within which phosphate rock is known to occur to any great extent. Between Midway and Spring Station, along the Louisville and Nashville Railroad, and on certain farms to the north of the railroad, is another area where phosphate rock has been found in some quantity. The limits of these areas have not been very accurately determined, but enough drilling has been done to indicate that locally, very important deposits of phosphate rock should be expected. When it is recalled that brown rock phosphate may be expected to run from 600 to 1,000 tons per acre per foot of thickness, small acreages may prove of great importance if the phosphate deposits are thick enough and of good quality.

In the fields and districts named there are many small areas in which the phosphate bed is lacking, or too thin to be of value, or perhaps is overlain by a cover too thick to remove profitably. Some prospecting has been done throughout all the areas and the distribution of the phosphate is quite well known in certain tracts. The work has been done privately, and hence the records are not available. As an example of the quantity of phosphate rock occurring in this region, it has been told the writer that 16,000 to 18,000 tons of phosphate rock were produced from a five-acre tract at Wallace, that is to say an average of 3,600 tons per acre. It has also been stated that 1,200 to 1,400 tons per acre foot are found

*Shirrer, J. J. and Sullivan, M. X. The action of manganese in soils, U. S. Dept. of Agriculture, Bull. 42, 32 pages, 1914.

in this region, and the excess over that usually occurring in the Tennessee brown rock field is due to the greater hardness and density of the Kentucky rock as compared with that in Tennessee. For the accuracy of these figures and statements the writer cannot vouch.

Outside of the Wallace area and that to the west of Midway, phosphate rock is known to occur in and around Lexington, Fayette County. Phosphate rock deposits are also known in the vicinity of Georgetown, Scott County, near the Forks of Elkhorn, Franklin County, near Versailles, Woodford County, and near Pine Grove Station, Clark County. The results obtained from prospecting in these different areas are outlined beyond and comments made as appears necessary.

In this report the Wallace area will be understood to include the area between Midway on the north and Versailles on the south, with Wallace as a geographical center. It will comprise the territory between South Elkhorn Creek on the east and an indefinite boundary west of the Versailles and Midway pike. It was near Wallace—a short distance to the east of it and near the Georgetown-Versailles branch of the Southern Railway —that the first phosphate of the Kentucky field was mined and sold. The low rolling topography of this region affords ideal conditions for the development of commercial phosphate deposits, assuming its original presence in the limestone. The region is also notably fertile and in the district along the Midway-Versailles pike the name "asparagus bed" of the blue grass region has been applied, owing to its marked degree of fertility.

The following sections, together with the map, show the general distribution of the phosphate rock together with its character, variations, and composition as determined chiefly by prospecting with the drill.

All sections and analyses numbered 100 or over refer to drill records and the samples obtained from them.

SECTIONS AND ANALYSES OF PHOSPHATE ROCK.

Wallace District.

No. 8. Central Kentucky Phosphate Co., ½ mile east of Wallace Crossroads, Woodford County, Ky.

No. 9. Central Kentucky Phosphate Co.

No. 10. Central Kentucky Phosphate Co.

No. 11. Central Kentucky Phosphate Co.

No. 12. Central Kentucky Phosphate Co.

No. 8—

4½′—Overburden.

2½′—Phosphate rock, 59.78% $Ca_3(PO_4)_2$.

Limestone.

No. 9—

6½′—Overburden.

4′ —Phosphate rock, 65.25% $Ca_3(PO_4)_2$.

Limestone.

No. 10—

1½′—Overburden.

2½′—Phosphate rock, 71.88% $Ca_3(PO_4)_2$.

Limestone.

No. 11—

6′ to 7′—Overburden.

2′-7″—Phosphate rock, 72.86% $Ca_3(PO_4)_2$.

Limestone.

No. 12—

12′ to 13′—Overburden.

5′-7″—Phosphate rock, 72.85% $Ca_3(PO_4)_2$.

Limestone.

No. 20. R. S. Stark quarry, east side Versailles-Midway pike, 3½ miles southwest of Midway, Ky.

2′-4′..............Overburden.

2′..............Phosphate rock, 66.48% $Ca_3(PO_4)_2$.

Limestone.

No. 22. R. S. Stark quarry, east side Versailles-Midway pike, 3½ miles southwest of Midway, Ky.

5′..............Overburden.

4′..............Phosphate rock, 58.55% $Ca_3(PO_4)_2$.

Limestone.

No. 23. Clinton M. Hawkins farm, 3 miles southwest of Midway, or ½ mile south of Wallace, Woodford County.

1′ 6″ Overburden.

1′ 6″ Phosphate rock, 59.88% $Ca_3(PO_4)_2$.

Limestone.

No. 100. S. C. McKinnivan estate, 1 mile southeast of Wallace.

10'..............Clay overburden with chert.

1'..............Phosphate rock, containing 17.79% $Ca_3(PO_4)_2$.

Limestone.

No. 104. S. C. McKinnivan estate, 1¼ miles southwest of No. 100.

7'..............Clay.

2' 1" Low grade phosphate rock.

6' 3" Phosphate rock, lower part of which is brown phosphate muck.

Limestone.

Analyses—

No. 104. 2' 1" layer. 31.86% $Ca_3(PO_4)_2$.

No. 104A. Highest grade material in drilling. 53.47% $Ca_3(PO_4)_2$.

No. 104B. Muck from lower part of drilling. 49.04% $Ca_3(PO_4)_2$.

No. 101. Will Steele's estate, south side Frankfort and Lexington pike, 1¼ miles southeast of Wallace.

1' 10" Clay.

0–8" Phosphatic Clay.

3' 9" Phosphate rock, 48.46% $Ca_3(PO_4)_2$.

Limestone.

No 102. Will Steele's estate, ¼ mile south of No. 101.

3' 4" Clay.

10' 4" Phosphate rock, 48.06% $Ca_3(PO_4)_2$.

Limestone.

A grab hand sample selected from the core drilled showed 48.18% $Ca_3(Po_4)_2$.

No. 103. Will Steele's estate, ¼ mile west of No. 101.

4' 5" Clay.

2' 2" Phosphatic clay and low grade phosphate .... Upper 2' 2", 53.47% $Ca_3(PO_4)_2$.

5" Phosphate rock — Lower 5", 65.16% $Ca_3(PO_4)_2$.

Limestone.

No. 105. R. S. Stark estate, 1¾ miles southeast of Wallace, north of Frankfort and Lexington pike.

2' 7" Clay.

2'..............Phosphate rock containg sand and clay, becoming clay at base, 31.49% $Ca_3(PO_4)_2$.

2' 11" Clay.

Limestone.

No. 106. R. S. Stark estate, ⅛ mile north of No. 105.

6' 5" Clay.

No phosphate rock.

Limestone.

No. 107. R. S. Stark estate, ⅜ mile northwest of No. 105.

1' 4" Clay.

4' 6" Phosphate rock.............. Upper half, 42.92% $Ca_3(PO_4)_2$. Lower half, 23.80% $Ca_3(PO_4)_2$.

Limestone.

No. 108. Estate of the late Mrs. Margaret Murray, $1\frac{1}{4}$ miles southeast of Wallace and north of Frankfort and Lexington pike.

9'..............Clay.

7' 8" Phosphate rock.

2'..............Clay and some phosphate.

Limestone.

Three different grades of phosphate rock came from this drilling containing 31.47%, 41.46%, and 63.87% $Ca_3(PO_4)_2$, the latter from a 2' 10" layer overlying the 2' clay bed.

No. 109. Estate of the late Mrs. Margaret Murray, $\frac{3}{8}$ mile northwest of No. 108.

2' 10" Clay.

1' 5" Chert.

1' 10" Clay and chert.

3' 6" Phosphate rock.

Limestone.

Two different grades of phosphate rock came from the hole, containing 54.48% and 54.06% of $Ca_3(PO_4)_2$.

No. 110. Estate of the late Mrs. Margaret Murray, $1\frac{1}{2}$ miles east of Wallace, near corner of farm.

11' 4" Clay.

4'..............Low grade phosphate rock.

Limestone.

Two different grades of phosphate rock came from the hole, containing 21.30% and 30.40% $Ca_3(PO_4)_2$.

No. 111. Estate of the late Mrs. Margaret Murray, 580 feet south of No. 110.

3' 5" Clay.

2'..............Phosphate rock.

Limestone.

Three different grades of phosphate rock came from the hole, containing 20.30%, 37.62%, and 20.43% $Ca_3(PO_4)_2$.

No. 112. Henry L. Martin estate, $\frac{3}{4}$ mile east of Wallace, north of Frankfort-Lexington pike.

8' 9" Clay.

2' 9" Phosphate clay.

3' 2" Phosphate sand, 50.30% $Ca_3(PO_4)_2$.

3' 9" Sand and plate rock, 60.87% $Ca_3(PO_4)_2$.

Limestone.

No. 114. H. L. Martin, Jr. estate, $\frac{1}{4}$ mile south of house.

1' 11" Clay with phosphate rock at base.

4" Phosphate rock, 25.78% $Ca_3(PO_4)_2$.

Limestone.

No. 115. Gate to H. L. Martin, Jr. estate, $1\frac{1}{2}$ miles southwest of Midway.

12' 8" Clay.

4' 2" Phosphate rock, 37.43% $Ca_3(PO_4)_2$.

Limestone.

No. 116. H. L. Martin, Jr. estate.

5′ 11″ Clay.

3′ 1″ Phosphatic sand, 35.16% $Ca_3(PO_4)_2$.

3′ 9″ Clay and phosphate rock, 44.30% $Ca_3(PO_4)_2$.

3′ 1″ Phosphate sand and plate rock, 56.50% $Ca_3(PO_4)_2$.

Limestone.

No. 118B. H. L. Martin, Jr. estate, 1/8 mile south, 15° E. from the railroad crossing.

2′ 7″ Clay.

11″ Phosphate rock, 56.19% $Ca_3(PO_4)_2$.

Limestone.

No. 119. H. L. Martin, Jr. estate.

6′ 2″ Clay.

2′ 1″ Phosphate rock, 43.53% $Ca_3(PO_4)_2$.

Limestone.

No. 120. H. L. Martin, Jr. estate, N. 10° E. from the house.

10′ 5″ Clay.

7′ 11″ Phosphate rock........ { Upper 3′ 0″, 28.92% $Ca_3(PO_4)_2$. Lower 4′ 11″, 40.62% $Ca_3(PO_4)_2$.

Limestone.

No. 121. H. L. Martin, Jr. estate.

5′ 1″ Clay.

3″ Phosphate rock, 40.19% $Ca_3(PO_4)_2$.

Limestone.

No. 122. H. L. Martin, Jr. estate, 1/8 mile northeast of No. 121.

4′ 4″ Clay.

3′ 5″ Phosphate rock, 50.20% $Ca_3(PO_4)_2$.

Limestone.

No. 123. H. L. Martin, Jr. estate, 3/8 mile southeast of house.

3′ 9″ Clay.

3′ 3″ Phosphate rock....... { Upper 1′ 5″, 31.06% $Ca_3(PO_4)_2$. Lower 1′ 10″, 22.20% $Ca_3(PO_4)_2$.

Limestone.

No. 124. H. L. Martin, Jr. estate, east of Versailles and Midway pike, about 3/4 mile southwest of Midway.

8′ 6″ Clay.

6′ 3″ Phosphate rock; lower 4′ 7″ gave 34.38% $Ca_3(PO_4)_2$.

Limestone.

No. 125. H. L. Martin, Jr. estate.

5′ 9″ Clay.

2″ Phosphate rock, 24.36% $Ca_3(PO_4)_2$.

Limestone.

No. 126. James J. Nugent, just northeast of Wallace crossroads.

7′ 5″ Clay.

11′ 9″ Phosphate rock.

Limestone.

The three grades of phosphate rock from this drilling ran as follows: Phosphate sand 8″, 31.96%; phosphatic clay 3′ 2″, 43.34%; and phosphate rock, 7′ 2″, 54.25% $Ca_3(PO_4)_2$.

No. 127. Nugent Bros. estate, ½ mile south of Wallace crossroads.

8'..............Clay.

8' 3" Phosphate rock........ { Upper 4' 10", 45.00% $Ca_3(PO_4)_2$. Lower 3' 5", 65.92% $Ca_3(PO_4)_2$.

Limestone.

No. 128. A. T. Harris estate, 1¾ miles southeast of Wallace.

4' 5" Clay.

1'..............Phosphate rock, 47.32% $Ca_3(PO_4)_2$.

Limestone.

No. 129. A. T. Harris estate.

3' 7" Clay.

1' 3" Phosphate rock, 58.86% $Ca_3(PO_4)_2$.

Limestone.

No. 130. A. T. Harris estate, just west of house.

3'..............Clay.

8' 3" Phosphate rock....... { Upper 3' 7", 40.61% $Ca_3(PO_4)_2$. Lower 4' 8", 64.74% $Ca_3(PO_4)_2$.

Limestone.

No. 131. A. T. Harris estate, ¾ mile west of house.

6'..............Clay.

2' 5" Phosphate rock, 39.21% $Ca_3(PO_4)_2$.

Limestone.

No. 132. E. L. Lillard estate, 2½ miles southeast of Midway near South Elkhorn Creek.

4'..............Clay.

4' 9" Phosphate rock...... { Upper 2' 1", 45.13% $Ca_3(PO_4)_2$. Lower 2' 8", 36.27% $Ca_3(PO_4)_2$.

Limestone.

No. 133. E. L. Lillard estate, ⅜ mile west of No. 132.

7' 6" Clay.

4' 2" Phosphatic clay, 24.56% $Ca_3(PO_4)_2$.

3' 2" Phosphatic sand and plate rock, 36.78% $Ca_3(PO_4)_2$.

3' 3" Phosphatic sand and plate rock, 48.34% $Ca_3(PO_4)_2$.

Limestone.

No. 134. E. L. Lillard estate, ½ mile northwest of No. 133.

3' 4" Clay.

5' 2" Phosphate rock, 33.11% $Ca_3(PO_4)_2$.

Limestone.

No. 136. E. L. Lillard estate, 3 miles southeast of Midway.

3' 6" Clay.

3" Phosphate rock, 52.23% $Ca_3(PO_4)_2$.

Limestone.

No 138. E. L. Lillard estate, ½ mile west of Zion's Hill near South Fork of Elkhorn.

3'..............Clay.

1' 4" Phosphate rock, 39.82% $Ca_3(PO_4)_2$.

5'..............Phosphatic clay, 15.82% $Ca_3(PO_4)_2$.

Limestone.

No. 137. J. B. Sellers estate, 2 miles southeast of Midway near highway.

8'............Clay.

6' 2" Phosphate rock....... { Upper 1' 5", 48.67% $Ca_3(PO_4)_2$. Lower 4' 9", 37.69% $Ca_3(PO_4)_2$.

Limestone.

No. 144. R. S. Stark estate, just east of Versailles-Midway pike, 1½ miles southwest of Wallace, opposite old quarry.

8' 1" Clay.

14' 4" Phosphate rock, 50.77% $Ca_3(PO_4)_2$.

Limestone.

No. 145. R. S. Stark estate, 25 feet west of hole No. 144.

3' 5" Clay.

1' 2" Phosphate rock, 71.64% $Ca_3(PO_4)_2$.

Limestone.

No. 146. R. S. Stark estate, 1¼ miles south of Wallace, near Southern R. R.

5' 7" Clay.

1' 5" Low grade phosphatic material, 41.32% $Ca_3(PO_4)_2$.

Limestone.

No. 147. R. S. Stark estate, ¾ mile southeast of No. 146.

1' 10" Clay.

2' 8" Phosphate rock, 57.06% $Ca_3(PO_4)_2$.

1' 6" Clay and chert.

4' 2" Clay.

Limestone.

No. 148. R. S. Stark estate, ½ mile northeast of No. 147.

2' 2" Clay.

3' 3" Phosphate rock, 53.10% $Ca_3(PO_4)_2$.

8'.............Dark brown clay, 29.50% $Ca_3(PO_4)_2$.

Limestone.

No. 150. Lister Witherspoon, 1½ miles southwest of Wallace and west of Versailles-Midway pike.

4' 5" Clay.

3' 1" Containing some phosphatic sand merging into clay at base, 23.26% $Ca_3(PO_4)_2$.

Limestone.

No. 156. Lister Witherspoon estate, rear of residence.

5' 6" Clay.

1' 4" Phosphate sand and clay; this and the 2' 1" layer below gave 16.11% $Ca_3(PO_4)_2$.

11" Cherty material passing into clay gumbo.

2' 1" Phosphate rock and clay.

Limestone.

No. 151. McBrayer Moore estate, 1 mile southwest of Wallace.

6' 10" Clay.

No phosphate rock.

Limestone.

No. 152. George McLeod estate, 2¾ miles southwest of Wallace.

2′ 5″ Clay.

8″ Containing some phosphate sand, no analyses.

Limestone.

No. 155. George McLeod estate, in front of house near sink hole.

15′ 4″ Clay.

2′ 3″ Phosphate sand, 33.55% $Ca_3(PO_4)_2$.

Limestone.

No. 159. Estate of Thomas Dunlap, 3 miles S. E. of Wallace, north side of Frankfort and Lexington pike.

2′ 2″ Clay.

1′ 4″ Phosphate muck, 33.09% $Ca_3(PO_4)_2$.

Limestone.

A sample of phosphate rock collected from a 3′ 6″ bed exposed in excavating a barite vein near gate to farm gave 52.49% $Ca_3(PO_4)_2$.

No. 161. Estate of Wm. A. Dunlap, 2½ miles S. E. of Wallace, near South Elkhorn Creek.

1′ 11″ Clay, the lower part of which contains phosphate rock fragments.

1′ 6″ Clay and some fragments of high grade phosphate rock.

1′ 11″ Phosphate muck, probably low grade, 35.45% $Ca_3(PO_4)_2$.

Limestone.

No. 162. Estate of Wm. A. Dunlap, 2 miles east of Wallace.

3′ 10″ Clay.

1′ 7″ Fine phosphate sand.

3′ 4″ Phosphate muck and phosphate sand, 42.01% $Ca_3(PO_4)_2$.

4′ 5″ Low grade clay.

Limestone.

District West of Midway.

No. 142. Estate of Mrs. Chas. Nuckols, 1¾ miles northwest of Midway.

4′ 10″ clay.

1′ 6″ Phosphate rock.

Limestone.

The two grades of phosphate rock from this hole gave 52.43% and 48.16% $Ca_3(PO_4)_2$.

No. 143. Estate of Mrs. Chas. Nuckols, ¼ mile north of No. 142.

8′ 8″ Clay.

4′..............Phosphate and clay, rather low grade, 37.56% $Ca_3(PO_4)_2$.

2′ 2″ Phosphate sand, 51.13% $Ca_3(PO_4)_2$.

Limestone.

The two grades of phosphate rock from this hole gave 37.56% and 51.13% $Ca_3(PO_4)_2$.

No. 139. E. L. Davis estate, Rookwood Station, on L. & N. R. R., 1¾ miles N. W. of Midway.

2′ 2″ Clay.

1′ 10″ Phosphate rock, 40.35% $Ca_3(PO_4)_2$.

Limestone.

No. 140. E. L. Davis estate, ⅛ mile N. E. of No. 139, on railroad.

5′ 3″ Clay.

4′ 3″ Phosphate rock and sand, 64.30% $Ca_3(PO_4)_2$.

10″ Clay and plate rock, 37.90% $Ca_3(PO_4)_2$.

1′ 8″ Clay.

Limestone.

No. 141. E. L. Davis estate, on L. & N. R. R., in small sink ½ mile S. W. of No. 139.

11′............Clay.

4′ 8″ Phosphate rock................ { Upper 1′, 35.21% $Ca_3(PO_4)_2$. Lower 6″, 56.41% $Ca_3(PO_4)_2$.

Limestone.

No. 163. Chas. Thomas estate, 2½ miles N. W. of Midway.

11′ 11″ Clay.

1′ 4″ Black muck.

2′ 2″ Sandy phosphate, carries 38.22% $Ca_3(PO_4)_2$.

2′............Black muck, carries 50.75% $Ca_3(PO_4)_2$.

1′ 8″ Fine black muck and sand.

Limestone.

No. 164. Chas. Thomas estate, ½ mile S. W. of No. 163.

4′ 5″ Clay.

1′ 9″ Phosphate rock, carries 46.37% $Ca_3(Po_4)_2$.

Limestone.

No. 166. Chas. Thomas estate, north of Leestown pike, ¼ mile S. W. of No. 165.

11′ 2″ Clay.

1′ 7″ Low grade phosphate, carries 32.20% $Ca_3(PO_4)_2$.

4′ 6″ Clay with a few inches of phosphate sand.

Limestone.

No. 169. On the south side of the highway, between the highway and the L. & N. Railroad, ½ mile east of Spring Station.

7′ 9″ Clay.

5′ 4″ Phosphate rock, carries 43.14% $Ca_3(PO_4)_2$.

Limestone.

No. 170. Estate of Mrs. Harry Wise, just north of house, ½ mile N. E. of Spring Station.

3′ 5″ Clay.

2′ 5″ Containing disseminated phosphate muck, carries 58.12% $Ca_3(PO_4)_2$.

Limestone.

No. 171. Estate of Mrs. Harry Wise, ⅜ mile northeast of No. 170.

5′ 4″ Clay.

4′............Phosphate muck, carries 31.37% $Ca_3(PO_4)_2$.

Limestone.

No. 172. Estate of Dr. Samuel A. Blackburn, ¾ mile northeast of Spring Station.

10′ 3″ Clay.

1′ 7″ Phosphate rock, carries 38% $Ca_3(PO_4)_2$.

Limestone.

No. 173. South side of Leestown pike, 3 miles northwest of Midway.

10′ 4″ Overburden.

5′ 9″ Low grade phosphate muck and clay; lower part contains 31.78% $Ca_3(PO_4)_2$.

Limestone.

No. 174. Estate of Mrs. Annie Slack, 2½ miles northwest of Midway, south side Lexington pike.

4′ 2″ Clay.

3′ 5″ Phosphate rock, upper 2′ 8″, contains 44.15% $Ca_3(PO_4)_2$.

Limestone.

Frankfort District.

No. 175. Estate of Judge E. C. O'Rear, 3½ miles east of Frankfort.

5′..............Clay.

1′ 9″ Low grade phosphate rock, contains 45.41% $Ca_3(PO_4)_2$.

Limestone.

Note.—A hand sample of phosphate chips collected at the gate to the estate of Judge E. C. O'Rear gave 70.65% $Ca_3(PO_4)_2$.

Several drill holes put down on different parts of the estate were found to contain no phosphate rock.

No. 182. Estate of Judge T. H. Painter, 6 miles N. E. of Frankfort, north of South Elkhorn Creek.

2′..............Clay.

1′ 8″ Phosphate rock. { Upper 8″ contained 32.42% $Ca_3(PO_4)_2$. Lower 1′ contained 43.67% $Ca_3(PO_4)_2$.

Limestone.

No. 188. Estate of Judge T. H. Painter, 5¾ miles east of Frankfkort, just north of the South Fork of Elkhorn Creek.

2′ 2″ Clay.

2′ 7″ Phosphate rock, carries 53.98% $Ca_3(PO_4)_2$.

Limestone.

Several drill holes put down on different parts of the estate were found to contain no phosphate rock.

Forks of Elkhorn District.

No. 191. Estate of South Trimble.

Scattering fragments of phosphate rock in this drill hole yielded 56.79% $Ca_3(PO_4)_2$.

A few other drill holes on this estate gave no phosphate rock.

No. 192. Estate of George Hannon, 5¾ miles N. E. of Frankfort, near gate at entrance to estate.

5′ 9″ Clay.

1′ 10″ Fine phosphate sand and rock, containing 41.86% $Ca_3(PO_4)_2$.

Limestone.

Lexington District.

No. 13. J. B. Haggin estate (Elmendorf): Quarry on estate, ½–¾ mile east of Maysville pike.

3'..............Overburden.

2' 6" Phosphate rock, 51.40% $Ca_3(PO_4)_2$.

Limestone.

No. 27, 28, 29. Southern Railway (Louisville & Lexington line) near Cahill place, 1½ miles west of Lexington.

4'..............Overburden (clay and soil).

3' 6" Massive phosphate rock.

3' 9" Clay.

Limestone.

No. 27. Top 4' of soil less than 2% $Ca_3(PO_4)_2$. This indicates in a general way what may be expected in the top soil of this region.

No. 28. Chip from the 3' 6" bed: 53.15% $Ca_3(PO_4)_2$.

No. 29. Sample of the 3' 9" bed which may be considered phosphatic clay. 16.44% $Ca_3(PO_4)_2$.

No. 33. James P. Headley estate, east side Russell Cave pike, just outside Lexington city limits.

8'..............Overburden (clay and soil).

5'..............Phosphate rock, 35.14% $Ca_3(PO_4)_2$.

Limestone.

No. 34. Station No. 11, near Hulett's, interurban railway, between Nicholasville and Lexington, Ky.

5'..............Overburden.

3'..............Chiefly maganese and iron oxide concretions. Less than 1% $Ca_3(PO_4)_2$.

10'..............Clay.

5'..............Massive phosphate rock, upper 4 feet carries 30.98% $Ca_3(PO_4)_2$.

No. 40. R. W. Higgins quarry, 1½ miles northwest of Greendale, Fayette County.

1'..............Overburden.

3'..............Phosphate rock, 29.79% $Ca_3(PO_4)_2$.

Limestone.

No. 218. Estate of Judge Jas. H. Mulligan, N. E. of Lexington, between L. & N. R. R. and Russell Cave pike.

5' 10" Clay.

1' 3" Phosphate rock, containing 49.18% $Ca_3(PO_4)_2$.

Limestone.

No. 218A. Estate of Judge Jas. H. Mulligan, W. of No. 218, but E. of railroad.

8' 2" Clay.

4' 3" Phosphate rock, containing 45.06% $Ca_3(PO_4)_2$.

Limestone.

No. 219. Estate of Judge Jas. H. Mulligan, E. of point where Russell Cave pike crosses L. & N. R. R.

4′ 3″ Clay.

1′ 5″ Phosphate rock, containing 39.91% $Ca_3(PO_4)_2$.

Limestone.

No. 194. Just east of Mentelle Park, Lexington. (No analysis.)

1′ 4″ Phosphate sand.

Limestone.

(Note: Overburden has been scraped away here to obtain clay for brick.)

No. 195. 20 feet. E. of No. 194.

5′ 3″ Clay.

2′.............Phosphate rock, containing 31.44% $Ca_3(PO_4)_2$.

Limestone.

No. 196. 25 feet E. of No. 195.

2′ 10″ Clay.

5′ 6″ Phosphate rock, containing 30.04% $Ca_3(PO_4)_2$.

Limestone, overlain by a thin layer of worthless yellow clay.

No. 197. 25 feet E. of No. 196. (No analysis.)

3′ 3″ Overburden.

4′ 11″ Phosphate sand and clay.

1′.............Clay.

Limestone.

No. 198. Estate of H. G. McDowell, southeast of Lexington on the Richmond pike.

8′ 7″ Clay.

7′ 1″ Phosphate rock, lowest 5 ft., carried 48.64% $Ca_3(PO_4)_2$.

Limestone.

No. 199. Estate of J. D. Clark, 3½ miles N. W. of Lexington.

No phosphate.

No. 200. Estate of J. D. Clark, ¼ mile S. E. of No. 199.

4′ 4″ Clay overburden with some disseminated phosphatic sand near base.

8′ 11″ Phosphate muck, containing 37.56% $Ca_3(PO_4)_2$.

Limestone.

No. 201. Estate of J. D. Clark, ¼ mile N. W. of house.

6′ 10″ Overburden.

8′ 6″ Phosphate sand, muck, and some phosphate rock, containing 30.93% $Ca_3(PO_4)_2$.

Limestone.

No. 202. Estate of J. W. Coleman, N. of Lexington, between Newtown and Russell Cave pikes.

4′ 7″ Clay.

2′ 2″ Phosphate sand, carries 22.78% $Ca_3(PO_4)_2$.

2′ 3″ Barren Clay.

Limestone.

No 203. Estate of J. W. Coleman, N. of Lexington, between Newtown and Russell Cave pikes.

4′ 2″ Clay.

2′ 8″ Phosphate sand and lump rock, carries 49.25% $Ca_3(PO_4)_2$.

Limestone.

No. 204. Estate of Ernest Erdman, N. of Lexington and E. of Newtown pike. (No sample.)

1′ 5″ Clay.

1′–2′ 6″ A mixture of clay and phosphate rock fragments.

Limestone.

No. 206. Estate of P. P. Bradley, N. of Lexington and E. of Newtown pike. (No sample.)

1′ 3″ Clay.

1′ 1″ Phosphate rock in scattering fragments.

1′ 3″ Clay.

Limestone.

No. 207. Estate of P. P. Bradley.

4′..............Clay.

9″ Some phosphate rock.

3′ 11″ Barren clay.

1′ 4″ Phosphate rock, containing 45.13% $Ca_3(PO_4)_2$.

Limestone.

No. 208. Estate of P. P. Bradley.

5′ 10″ Overburden.

4′ 8″ Phosphate rock, containing 48.51% $Ca_3(PO_4)_2$.

Limestone.

No. 211. Estate of Capt. J. D. Yarrington, between Maysville and Russell Cave pikes.

5′ 1″ Clay.

7″ Containing some phosphate rock, containing 45.74% $Ca_3(PO_4)_2$.

Limestone.

No. 212. Estate of Capt. J. D. Yarrington.

6′ 10″ Clay.

2′..............Low grade phosphate rock, carrying 20.54% $Ca_3(PO_4)_2$.

5′ 6″ Clay with 1′ phosphate rock at base.

Limestone.

No. 213. Mr. Easton estate, N. E. of Lexington, W. of Maysville pike.

2′..............Clay.

2′ 8″ Phosphatic sand, containing less than 5% P_2O_5.

2′ 2″ Clay mixed with a little phosphate.

Limestone.

No 214. Estate of Judge George B. Kinkead, N. E. of Lexington, just E. of Russell Cave pike.

3′ 8″ Clay.

4″ Fine lump rock, containing 40.79% $Ca_3(PO_4)_2$.

Limestone.

No. 214A. Estate of Judge George B. Kinkead, about 50 feet further south on the hillside from No. 214.

2′ 5″ Clay.

1′ 6″ Phosphate rock (no sample).

Limestone.

No. 214A. Estate of Mrs. Martha Withers, northeast outskirts of Lexington.

2′ 2″ Clay.

2′ 7″ Containing phosphate in lower 1–2′, with 34.11% $Ca_3(PO_4)_2$.

Limestone.

No. 216. On the Russell Cave Pike, N. 80° W. of Mrs. Martha Withers' estate.

5′ 6″ Clay.

7″ Phosphate rock, no analysis.

Limestone.

No. 217. Estate of Mrs. Martha Withers, E. side of the estate near Maysville pike.

2′ 1″ Clay.

1′ 4″ Phosphate rock.

(Note: Struck water in this hole and did not get to bottom. No sample.)

No. 217A. Estate of Mrs. Martha Withers, nearer the Maysville pike.

1′ 10″ Clay.

9″ Phosphate rock, carrying 24.31% $Ca_3(PO_4)_2$.

Limestone.

No. 221. Estate of H. Gibson heirs, S. W. of Lexington.

17′ 3″ Clay.

Limestone.

(Note: About 15′ black muck in the lower part of the hole. Lowest 3–5′ contained 21.06% $Ca_3(PO_4)_2$.

No. 223. A. M. Miller estate, rear of house, South Limestone Street, Lexington.

6′ 7″ Reddish brown clay.

4′ 3″ Phosphate sand and clay, 30.93% $Ca_3(PO_4)_2$.

7″ Clay chiefly, but with some phosphate sand.

2′ 4″ Barren clay.

Limestone.

No. 224. Estate of A. M. Miller, S. W. of No. 223.

6′ 3″ Clay.

6′ 4″ Chiefly clay, with some phosphate sand, no analysis.

1′ 2″ Phosphate sand.

Limestone.

No. 226. Kentucky Agricultural Experiment Station grounds.

5′ 7″ Clay.

7″ Disseminated phosphate sand with heavy chert.

4½″ Variegated clay and rotten chert.

Limestone.

(Note: No sample. No phosphate rock.)

No. 227. Kentucky Agricultural Experiment Station grounds, 1/8 mile S. W. of No. 226 along the road.

6′	1″	Clay.
	8″	Phosphate sand.
4′	4″	Low grade phosphate sand and clay.
2′	2″	Barren clay.
	9″	Phosphatic muck and yellow clay, containing 35.10% $Ca_3(PO_4)_2$.
1′	8″	Yellow drab clay.
2′	9½″	Clay and heavy chert.
		Limestone.

No. 228. Estate of Joe C. Van Meter, S. of Lexington, and W. of Tates Creek pike.

8′	4″	Clay.
		Limestone.
		No phosphate rock.

No. 229. Estate of Joe C. Van Meter, S. of Lexington and W. of Tates Creek pike.

5′	11″	Clay.
8′	....	Iron manganese concretions.
		Limestone.

Two characteristics stand out above all the others in the sections given above, these are the great variation in thickness and composition of the phosphate rock. This is characteristic of the entire brown rock phosphate area. To obtain a better idea of the composition of the different grades of rock it would have been desirable to wash each sample as drilled, thereby separating muck, sand, and lump rock. This is done in practice in preparing the mined rock for market for conversion to acid phosphate. It could not be done by the writer in the field without much inconvenience. The analyses of the hand specimens of lump or plate rock throw some light on what might be expected from the lump rock in the sections, and where the specimens were collected and their analyses compared with a few of those of the lump rock itself selected from the drillings, the results show fairly close agreement.

LOCALITIES TO BE PROSPECTED.

It must not be inferred that all the promising localities in the blue grass region have been examined and prospected, for such is not the case. The co-operative

work carried on by the United States and Kentucky Geological Surveys was limited by the available funds, and it is known that prospecting by private parties has been carried on in other areas and which without doubt has yielded results which may be as promising or much more so than those obtained in this investigation. In a cut on the Louisville and Nashville Railroad, within the town of Versailles, beyond the iron bridge one-eighth of a mile west of the concrete highway bridge, samples were collected from probably the Woodburn member since *columnaria halli* was observed. Of three samples collected one gave 27.14 per cent., another (No. 25) gave 73.30 per cent., and a third yielded 20.84 per cent. calcium phosphate. The selected chips in sample No. 25 indicate what the lump rock may run in this region. South of Versailles, on the west side of the Nicholasville pike, on the farm of Ball brothers, chips were noted in abundance on parts of the farm, especially in the rear of a group of small cabins. The samples collected here gave a 79.49 per cent. calcium phosphate. To the northwest of Versailles, where the Midway pike leaves the trolley line, a sample collected near the Fishback place yielded 76.23 per cent. calcium phosphate. Other analyses of selected samples not included in the tables above are given below. It should be remembered that these are selected hand samples of chips which represent lump rock alone and not the run of a drill hole or pit.

SELECTED SPECIMENS OF PHOSPHATE CHIPS.

Wallace District.

	Per Cent. of Phosphate of Lime. $Ca_3(PO_4)_2$.
No. 47	61.53
No. 48	76.12
No. 49	64.03
No. 50	12.37
No. 51	80.67
No. 52	77.47
No. 56	77.64

No. 47. R. S. Stark estate, 1½ miles south of Wallace, at side of private road through farm. Taken from the bottom of a post hole.

No. 48. Locality same as No. 47. Selected chips from a pile of phosphate rock thrown out in excavating.

No. 49. Mrs. M. Murray's estate. Sample collected from the bottom of an old prospect pit just west of the house, 1½ miles east of Wallace.

No. 50. Mrs. M. Murray's estate, 1½ miles east of Wallace. Chips collected from surface. Thrown out in making an excavation in the northeast corner of the farm near road.

No. 51. Thomas Dunlap estate, 2½ miles southeast of Wallace, near South Elkhorn Creek, in rear of house and barn; south hillside of a small branch shown on the map.

No. 52. William Steele farm, about 2 miles southeast of Wallace. Chips thrown out in digging an old phosphate pit.

No. 56. E. L. Lillard farm. Fragments collected ⅛ mile northeast of the main gate at the entrance to the mansion.

SELECTED SPECIMENS OF PHOSPHATE CHIPS.

Lexington District.

	Per Cent. of Phosphate of Lime. $Ca_3(PO_4)_2$.
No. 1	48.59
No. 15	71.91
No. 32	71.14
No. 41	57.25
No. 42	73.34

No. 1. Brown lump rock, cut in the Louisville Southern Railway near the Cahill farm, 2 miles northwest of Lexington, between the Frankfort and Versailles pikes.

No. 15. Main Street, Lexington. Fragments of supposed phosphate rock from a sewer excavation nearly opposite Kaufman's clothing store.

No. 32. Rear of the plant of the Lexington Power Company, just west of North Limestone Street about a mile from the center of the city.

No. 41. On the Lexington-Richmond turnpike within the city limits, at the end of East Main Street, about 100 yards east of Mentelle Park.

No. 42. About 1 mile south 20° east of Ashland, former home of Henry Clay. The material was selected from that thrown out in excavating for a pumping station.

SELECTED SPECIMENS OF PHOSPHATE CHIPS.

Georgetown District.

	Per Cent. of Phosphate of Lime. $Ca_3(PO_4)_2$.
No. 18	48.97
No. 43	70.26

No. 18. L. V. Harkness estate (Walnut Hall), about 7½ miles due north of Lexington. Massive type of phosphate rock.

No. 43. Fred S. Crunbaugh estate, near North Elkhorn Creek, about 2½ to 3 miles east of Georgetown, Scott County.

SELECTED SPECIMENS OF PHOSPHATE CHIPS.

Forks of Elkhorn District.

	Per Cent. of Phosphate of Lime. $Ca_3(PO_4)_2$.
No. 44	72.98

No. 44. G. L. Hannen farm, 4½ miles east of Frankfort, south side of the pike, at the side of the lane going into the farmhouse.

SELECTED SPECIMENS OF PHOSPHATE CHIPS.

Pine Grove Station, Clark County.

	Per Cent. of Phosphate of Lime. $Ca_3(PO_4)_2$.
No. 53	71.50
No. 54	40.88

No. 53. Sample overlying limestone a few hundred feet east of Pine Grove Station and on the opposite side of the railroad.

No. 54. Material from place above the limestone a few paces east of where the surface chips constituting No. 53 were collected.

It follows from the analyses of hand samples collected in various localities where systematic prospecting with the drill was not carried on, that several areas will bear further close examination. Northwest of Versailles between the Midway pike and the trolley line to the west of it, the type of topography is a promising index and the region seems to have undergone the deep weathering necessary to the development of the phosphate rock deposits. All the low flat hills in this region are comprised in part in the geologic horizon of the phosphate rock and the latter should not be too deep for profitable mining, provided it proves to be of sufficiently high grade. This is a region which should be closely prospected, for example in the neighborhood of the George Fishback and the Senator Camden places.

According to Professor Miller, good phosphate rock should be found on both sides of the Elkhorn Creek, that is between the Lexington-Georgetown pike on the east and the Lexington-Frankfort pike on the west. But little is known of any phosphate occurrences in this general area north of the Leestown pike.

The region around Hulett's, on the trolley line between Lexington and Nicholasville, is one which so far as known has never been thoroughly or even superficially prospected. It might prove to be worth going over to make sure that no important phosphate rock deposits are overlooked.

Other localities where prospecting might yield results are in the vicinity of the Forks of Elkhorn, Franklin County; near Georgetown, Scott County, and in the vicinity of Danville, Boyle County. The analysis of a sample found near Pine Grove Station, Clark County, given above is also of interest. The region about Donerail, Fayette County, is also worth attention. In a study like that carried on by the writer, it was impossible to prospect over every promising region, and only careful work will reveal the possibilities of the different sections of the blue grass region.

METHODS OF PROSPECTING.

In beginning this investigation rock hand samples were selected at natural or artificial exposures. It was soon found that such samples mean little or nothing in arriving at an adequate idea as to the real commercial character of the deposits. For this reason systematic prospecting with the drill was undertaken. The closeness with which the latter was carried on may be observed from the map. It will be appreciated that in a government investigation prospecting could not be carried on as closely as it would have been by private parties planning to determine tonnage in restricted areas with the view of operating. The methods employed under similar conditions in Tennessee are outlined further on. From the methods employed in Kentucky and the closeness with which the work was done, a good idea is obtained where the best deposits may be expected and where further development work ought to be carried on. Even with the most up-to-date methods of prospecting,

perfectly representative samples are difficult to get. It is doubtful whether, owing to the difficulty of properly apportioning the lump and muck rock, the content in calcium phosphate of the material can be represented in any hand sample.

In the Wallace area many hand samples were collected and more than 50 holes were drilled. In but comparatively few of the holes was no phosphate found at all. The limestone, however, outcrops very near the surface in places and leaves no room for any deposits to form, or if it ever was present, it has been removed by erosion. Toward the creek bottoms generally no deposits were encountered and approaching the hilltops or 900-foot contour, the overburden grows heavy and the deposits thin. The richest deposits were found generally between 840 and 860 feet in elevation. The sections given above for the individual farms shew the great variation in the thickness, character, and position of the phosphate rock encountered.

The methods employed in this investigation for prospecting for phosphate rock in central Kentucky were in part those commonly employed in the brown phosphate rock fields of Tennessee. Only drilling with augers was employed in Kentucky. Prospecting, of course, could not be carried on so extensively as by private parties. Prospecting on an extensive scale is expensive, and can only be done by those companies or land owners who plan to ascertain definitely the workability or non-workability of a given area. It is carried on in different ways, or by a combination of different methods.

One of the common methods of prospecting for brown rock, which may be employed in general for all soft and easily penetrated sedimentary deposits, where the overburden is also soft and not too thick, is by means of an ordinary 4-inch earth auger handled by two men. Three-quarter-inch pipe, in convenient lengths, may be screwed together as the auger descends to furnish the necessary additional length of pipe. The auger is provided with a T-handle to make it easy to bring the required pressure to bear. Where it is difficult to penetrate the formation, as where much chert is present, a 4-inch post hole digger may be used. This is merely a hollow

form of drill or cylinder about 10 or 12 inches long, provided with a slit. Samples are removed with comparative rapidity with these two tools, and the auger or digger is easily emptied after their load of material has been loosened by a cheap screwdriver. The work is carried on quite rapidly and the sample representing the phosphate bed is next treated as described.

The entire sample was spread on a piece of oil cloth and thoroughly mixed in the usual way. It was then quartered and the two opposite quarters discarded. This treatment was repeated until a final small portion was obtained which was in turn sampled by selecting portions from it here and there. The final sample, which was about four pounds in weight, was then sacked and sent to the laboratory. In certain cases where the original drill sample was very large, more than one sample may have been selected and where the material from a drill hole consisted of definite layers of lump rock, sand, and muck, the attempt was made to secure representative samples of each of these different varieties.

In ordinary blanket deposits it is the custom in Tennessee to sink the drill holes about 200 feet apart in squares; but in rim, collar, or hat band deposits the holes are spaced 200 feet apart throughout the length of the deposit and from 50 to 200 feet apart on their short axes.

In conjunction with drill holes, test pits have to be sunk where the prospecting is done with proper care. A pit is dug every 400 feet to obtain samples for recovery or washing tests. Such samples are much better than those obtained by drilling for they represent what may be expected from actual mining operations. By washing such material, the quantity of lump rock, sand, and muck may be measured and their composition or content in bone phosphate may be determined. The recovered products are dried, weighed, and analyzed separately and the percentages of recovery calculated. Konwing the weight of a cubic foot of the material in the ground, the percentage of recovery may be converted into such convenient terms as an acre foot of recoverable material, that is the quantity recoverable per acre per each foot of depth (43,560 cubic feet).

It is estimated that the cost of prospecting averages

7 to 7½ cents per foot of hole with augers, or $1.50 to $2.00 per acre for average conditions.

Especial care is required to determine the average thickness of most areas where the rock is known to lie in cutters. The phosphate rock may constitute from 30 to 50 per cent. of the total volume below the top of the limestone table.

The samples from prospecting are prepared for analyses by washing in an ordinary wash tub. The sand is saved by decantation and the lump is separated by the aid of a hose and an eight-inch slotted screen. The recovered products are dried, weighed, and analyzed separately. Tonnages are calculated on the basis of a recovery of 1,000 long tons of dry rock per acre foot for high grade deposits, but for average grades this will be more nearly 850 tons per acre foot. For more accurate work the percentages of recovery should be used as determined in the laboratory, allowing 15 to 20 per cent. in actual mining and treatment.*

METHOD OF COLLECTING SAMPLES.

In collecting the samples without the drill, for example in the old workings at Wallace, the face of the workings was carefully exposed with pick and shovel, and a space was cleared of debris at the base of the exposures to be sampled. About 5 pounds of rock were picked off from each foot of section exposed, care being taken to procure adequate representation of lump, sand, and fine muck. The larger fragments were then broken to the size of a walnut and all the grades were then mixed, quartered, and the opposite quarters discarded. This operation was repeated until the two remaining quarters were of the proper size for analysis and examination. Similar methods were employed with the cores of phosphate rock obtained in drilling.

THE LOCAL QUARRY INDUSTRY AS A GUIDE TO PROSPECTING.

Natural exposures are comparatively rare in this part of Kentucky, but many small quarries have been opened in this region which are in most cases located

*Figures are taken from Barr, James A., Tenn. Phosphate Practice., Amn. Inst., Min. Engrs., Bull. 93, Sept., 1914, pp. 2397-2413.

near the public highways where they are rarely missed by the geologist. There is a reason for this. The estates which border the main public pikes have stone fences and the material entering into their construction has come from a neighborhood quarry. To save transporting the stone long distances the quarry is usually located near the highway. An examination of the soil overlying the limestone in these quarries may often furnish a safe index of the presence or absence of phosphate in a locality. It is a criterion, however, which has to be used with care, but the writer found it a help in indicating the possible presence or absence of phosphate in different localities. The difficulty with such an index is the relative scarcity of quarries, and it becomes a sound basis of judgment only as the number of quarries increases.

THE COMPOSITION OF THE PHOSPHATE ROCK.

The material collected from the drillings shows great variation in content of calcium phosphate. From the method of collecting the samples it is to be expected that the analyses would run low. In the Wallace district, of the total number of analyses made of materials collected from drillings, about 35 per cent. showed a content of 50 per cent. or more of calcium phosphate. Less than 10 per cent. of the total showed a content between 60 and 70 per cent. and but 5 per cent. of the total showed more than 70 per cent. The latter material was for the most part collected from well exposed sections in the old workings of the Central Kentucky Phosphate Company, near Wallace. The remaining 65 per cent. contained less than 50 per cent. calcium phosphate, the great bulk of the material having from 30 to 50 per cent.

The number of drillings made in the other districts was not very large, not large enough to base close estimates on. The results obtained are outlined below. In the area between Midway and Spring Station, where prospecting was carried on, about 25 per cent. of the samples obtained in drilling contained between 50 and 60 per cent. calcium phosphate, and about 5 per cent. between 60 and 70 per cent. The remaining 70 per cent. contained less than 50 per cent. calcium phosphate.

The great bulk of the material collected from drillings in the vicinity of Lexington contained less than 50

per cent., which is likewise true for the Forks of Elkhorn district. The reader may reach his own general conclusions from a study of the analyses given above, bearing in mind that all the sections and analyses numbered 100 and more refer to drill records and the samples obtained from them. In the case of selected specimens from old excavations or natural exposures, the results are given elsewhere. They indicate that the washed lump rock, which is virtually what most of the latter material represents, contains more than 70 per cent. calcium phosphate in many localities and one sample collected from the Thomas Dunlap farm, 2½ miles southeast of Wallace, near South Elkhorn Creek, gave 80.67 per cent. calcium phosphate. This high content in bone phosphate does not appear to be wholly unique, for in a table comprising 6 analyses Waggaman* states that hard, brown, heavy plates of phosphate rock collected on the Slack farm, 3 miles northwest of Midway, contained 81.08 per cent. calcium phosphate. Foerste† likewise reports a sample running 82.37 per cent. calcium phosphate from the same farm. It is probable that the two samples were collected from the same pit. Foerste likewise reports a sample from the Lister Witherspoon farm, near the Versailles-Midway pike, which contained 80.80 per cent. calcium phosphate.

Thus it appears that while occasional occurrences of lump rock are found containing more than 80 per cent calcium phosphate and although rock in workable quantities will be found running up to present commercial requirements, that is containing 70 per cent. and more BPL, it is quite safe to affirm that the bulk of Kentucky phosphate rock will be found to contain less than 70 per cent. BPL. This means that in the most promising areas the rock will have to be carefully washed and cheaply worked by the most modern, labor-saving devices to bring it up to present commercial standards so that it may be able to compare with Tennessee rock. Without doubt much of the Kentucky rock of low or intermediate grade must wait for cheap chemical or electrical processes of concentration.

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*Waggaman, W. H. A report on the natural phosphate of Tennessee, Kentucky and Arkansas. U. S. Dept. of Agriculture, Bureau of Soils, Bull. 81, p. 25, 1912.

†Kentucky Geol. Survey, Series IV., Vol. I., Pt. I., 1913, pp. 431-439.

ORIGIN.

Source of the Phosphate.—The phosphate was deposited originally on the floor of a shallow sea. Some of it may have been chemically precipitated directly from solution, and some may have come from phosphate secreting organisms which flourished in the water of the Ordovician sea. The phosphate probably came from both these sources. Such organisms exist at the present time and some of them have been shown to have shells consisting largely or almost wholly of calcium phosphate.

F. W. Clarke and W. C. Wheeler* have shown that the element phosphorus occurs in abundance in the shells of certain brachiopods, crustaceans and alcyonarians. Certain worm tubes are also notably phosphatic· The exact original nature of the phosphates is not known since there is not enough basic material present to have formed the normal tricalcium phosphate. Ultimately it reaches this form in the sediments. Some of the phosphatic alcyonarian corals contain from 7.95 to 13.35 per cent. calcium phosphate. Certain of the brachiopods, especially the lingulas and glottidias, are highly phosphatic, containing from 74.73 to 91.74 per cent. calcium phosphate, and some of the phosphate present is represented as a magnesian salt. The analyses of crustaceans given show a range of 6.57 to 27.44 per cent. calcium phosphate, with an exceptional analysis of a shrimp shell showing 49.46 per cent. calcium phosphate. Some worm tubes show as much as 20.72 per cent. calcium phosphate.

These results are interesting not only quantitatively, but qualitatively as well. Without doubt even minute quantities of calcium phosphate in the shells of animals have an important geologic and economic significance since in connection with the formation of all our phosphate deposits and other economic minerals as well, the factors of time and process of mechanical concentration are highly important. Even with only minute quantities of calcium phosphate originally present, slow processes of concentration acting over long periods of time produce important results.

Original Mode of Occurrence.—The original phosphatic material as now seen in nature, that is the phos-

*U. S. Geol. Survey Professional Paper No. 102, 1917, p. 50.

phatic material as originally deposited, occurs in definite bands in the limestone mixed with calcium carbonate. There is little question that these highly phosphatic bands are original and that they were laid down alternately with bands of limestone containing, to be sure, some phosphate, but essentially less phosphatic than the intervening layers. The illustrations taken in the Mt. Pleasant, Tennessee, brown rock field, in the Wallace, and other localities in Kentucky (see Plates VII. and VIII.) illustrate this alternate banding. Typical cross bedding of the phosphate and calcium carbonate layers was also observed at the Wallace workings. The abundance of the cyclora casts not infrequently gives the rock an oolitic and almost botryoidal appearance, but the little rounded particles are not necessarily true oolites, and they are usually not. The alternating rich and lean phosphate layers thicken and thin and pinch out abruptly—in a word they have all the characteristics of a normal cross bedded, sedimentary rock deposited where there was some current action.

Many samples were collected showing the marked difference in the phosphate content between these alternating layers and in a specific case which may be taken for illustration, a sample of the purest phase of the limestone in a given ledge yielded less than 1 per cent. calcium phosphate, whereas the phosphate layers interbedded with it yielded 72.21 per cent. calcium phosphate. That is, of course, an extreme difference and it is quite likely that all the transitional compositions may be found in these layers, from pure limestone at the one end to the very highest grade phosphate at the other.

In the bands or layers which are notably phosphatic, a certain minute fossil—a coiled gastropod of the genus cyclora—is markedly abundant. In some specimens the casts of the interior of these shells are so numerous as to give hand specimens an oolitic appearance. Whether the shells of these small organisms were originally phosphatic cannot be stated with certainty. The fact that the exterior shells have dissolved and left only casts of the interior tends to indicate that the exterior shells were calcareous. Their abundance and structure rendered them admirable receptacles for the finely divided and perhaps almost impalpable calcium phosphate

deposited on the floor of the Ordovician sea which hardened in the shapes of the interior of the shells in which forms they are now found. The mechanical role which these minute organisms played in the concentration of calcium phosphate was apparently a very important one. Whether the chemical role was of any importance cannot be stated, nor may it ever be known. Clarke and Wheeler's results do not indicate that the gastropod tests which they examined are important carriers of calcium phosphate. It may even be true that the occurrence of the phosphate at certain horizons may be due to mechanical concentration effected by the abundance of these coiled gastropods, they having served as natural receptacles for it. Large organisms—the brachiopods—likewise acted mechanically as receptacles for the finely divided phosphate and the illustration shows the cast of the interior of a brachiopod—*rafenisquina alternata*—collected by A. M. Miller near Versailles, Woodford County, Kentucky. The shell itself has been replaced by silica, a portion of which still remains as the white patch in the illustration, (Plate XI.) The cast of the interior has been formed by calcium phosphate which forms the mass of the specimen.

The Method of Concentration.—The evidence reveals that a great deal of calcareous material was deposited with the phosphate and that the latter, as it now occurs, is the result of leaching the calcareous parts of the originally phosphatic limestone. Some of the phosphate as now observed may have been originally quite rich and some of the leaching may have occurred while the deposits were yet exposed to current action on the ocean floor. This, however, is pure speculation. It is known that as a result of subaerial leaching the disseminated phosphate has been concentrated as the calcareous parts have dissolved away, and there has resulted a fair grade phosphate deposit from what was a low grade material. In other words, the brown phosphate rock deposit of Kentucky, as it occurs today, represents a clear case of secondary concentration or enrichment.

Several factors have played parts in the leaching or dissolving of the calcium carbonate deposited with the phosphate. It is presumed that the solution took place by conversion of the normally insoluble lime carbonate

to the soluble bicarbonate according to the chemical reaction. $H_2CO_3+CaCO_3=CaH_2(CO_3)_2$. The carbon dioxide was furnished by percolating meteoric waters. Thus the first factor is a position near enough to the surface to be brought into contact with surface waters. In describing the stratigraphy of the phosphate area, the Brannon member was stated to underlie the richest phosphate horizon in central Kentucky. It was there described as a firm, hard limestone, a good water bearer with its outcrop marked by springs. It is the limestone occurring in the numerous sinks of this region.

The overlying member, the Woodburn, which carries the phosphate principally, is granular, thin bedded, and likewise contains sinks. In other words it is of a character to readily weather and dissolve away. This combination of an underlying more or less impervious stratum and an overlying granular limestone is an advantageous one for the rapid accumulation of phosphate and no doubt was an important factor in the segregation of the phosphate deposits. Thus the character of the associated sediments may be considered the second important factor in the rapidity with which the phosphate rock may concentrate.

Two other factors have helped the leaching process, namely, the laminated character of the limestones and associated phosphate layers already referred to, and the joint planes which are characteristic of these limestones, as they are of most rocks. The leaching of the calcareous portions begins along the joint planes between the laminae, especially along those planes between the limestone and the phosphate bands, which afford easy means of attack. As the leaching progresses the solution cavities along the joint planes grow wider and deeper and ultimate in the "cutters" which have been already described. The undissolved masses of limestone remaining between the cutters are called "horses." The cutters have, as would be expected from the theory ascribed for their formation, very definite courses—too great a regularity to admit that their formation has been largely fortuitous. In the vicinity of Wallace the courses of the cutters were between north 8° west and north 25° west. In Mt. Pleasant, Tennessee, where much better opportunities exist to observe this phase of phos-

phate occurrence, the trends of the cutters follow quite definite directions also.

The limestones not only are leached from above and on the sides of the horses (cutters), but solution takes place laterally, or along the limestone and phosphate laminae, so that actual projecting ledges or umbrella rocks form on the sides of the horses. Sometimes leaching proceeds to the point where limestone masses actually become completely detached through solution and lie amid the deposits of the phosphate rock.

The irregularities of the underlying rock surface and the manner in which the phosphate settles down on it, has given rise to the undulations which occur in the phosphate rock deposits. These phenomena are well brought out in the illustrations. The intervening clay layers associated with the phosphate rock represent the original beds of non-phosphatic clay bearing limestone. This material weathers to a product commonly referred to as muck.

Disseminated phosphate sand is associated with plate, lump or hard rock and with the muck. Most of this disseminated sand without doubt represents originally disseminated phosphate rock scattered throughout the deposits and which has become concentrated through the leaching of the limestone. Most of the sand is simply Cyclora casts composed of phosphate, again illustrating the important mechanical role played by these minute organisms in the concentration of this valuable fertilizer. The term sand is not a good one from the view point of origin, for though most of the little fragments are rounded as fragments of such casts would be expected to be, the rounded shapes are not due to mechanical attrition, but are original.

Some very interesting observations on Kentucky rock have been made by Arthur M. Miller.* Miller believes in an original segregation of the phosphate deposits, that is, a segregation at the time they formed on the ocean floor. He says, "this original segregation of the phosphate has in no case, however, given deposits rich enough to be commercially valuable. The latter deposits have resulted from the weathering of the deposits of the first concentration. Though concentrated as the

*Ky. Geol. Survey, Series IV., Vol. I., Pt. I., 1913, pp. 327-328.

result of weathering, we do not believe that the facts of occurrence warrant the explanation that in weathering the 'carbonate of calcium has been dissolved out leaving the phosphate of lime behind'—that in other words it is simply a residual deposit due to the leaching out of a more soluble constituent.

"Were the latter the case it should be possible to find many instances of deposits of unleached phosphate where the amount of phosphate in the same volume of deposit equals that which we do now find in the weathered commercial deposits. The same amount of phosphate should be there plus the original amount of carbonate of lime; but in no instance is this the case. On the contrary, all the facts point to an actual concentration of the phosphate into less volume as the result of a process of replacement. We have here the same phenomenon as is illustrated by certain iron ore deposits. Water with iron in solution is checked in its downward descent by meeting relatively impervious stratum. Under these conditions the saturated stratum (commonly a limestone) immediately above the relatively impervious stratum is altered by replacement; iron replaces calcium, the latter being finally carried away in the form of bicarbonate by the water.

"So in the case of concentrated phosphate of lime deposits: insoluble tricalcium phosphate acted upon by organic acids in the superficial layers of rock waste has its phosphorus rendered soluble ('available'). Entering into solution in the form of phosphoric acid, it passes downward to the lower 'rottenstone' and bed rock layers. Here the phosphorus 'reverts' to its original tricalcium phosphate condition, replacing the non-phosphatic or relatively non-phosphatic limestone.

"The final theoretical reaction is expressed by the following equation: $Ca.\ H_4\ (PO_4)_2+2\ Ca.\ CO_3=(PO_4)_2+2H_2O+2CO_2$."

This theory of the formation of Kentucky phosphate rests on the solubility of calcium phosphate. Without any doubt this compound in its natural state is sufficiently soluble to bring about important accumulations over long periods of time, due to replacement, and possibly replacement has been an important factor. As pointed out above, in practically unaltered specimens of the phos-

phatic layers interbedded with limestone, the rich phosphatic layers are present. These were collected by the writer and analyses made in the survey laboratories showed more than 70 per cent. in calcium phosphate. Foerste* also reports unweathered limestone near Versailles from the Woodburn member carrying 55.5 per cent. calcium phosphate, overlain by rock containing only 9.39 per cent. of the same ingredient. Thus to the writer the idea of replacement is not an absolutely necessary factor in accounting for the concentration of the phosphate rock. He is willing to admit that replacement may have played a part, but feels that the explanation that has been given, and by which other writers have explained the formation of the Tennessee phosphate deposits, will apply to the Kentucky field.

THE BROWN PHOSPHATE ROCK INDUSTRY.

General Conditions.

The Kentucky phosphate field is practically a virgin field. From its study and a comparison of it with the Tennessee field, the writer feels that local conditions are similar and the problem of working the Kentucky deposits must be along much the same lines as in Tennessee. For this reason it is thought that a brief description of the mining methods employed in the Mt. Pleasant, Tennessee, field will prove of interest here.

There has been going on for some time in the Mt. Pleasant phosphate field and without doubt in other parts of the Tennessee brown rock phosphate areas, a change that will result in leaving very little or no wasted phosphate rock in the ground. Some phosphate is going into the waste ponds, but the time will without doubt come when all this material will be reworked, and even now some companies are working or planning to work these old tailings. Modern mining and milling methods of the last decade have revolutionized the brown rock phosphate industry, and incidentally are conserving this valuable fertilizer material. They are in striking contrast with the crude and wasteful methods formerly employed. When phosphate was first mined in Tennessee it is safe to say that at least half of the good material such, for example, as is now being worked was thrown

*Loc. Cit., p. 381.

away. A great deal of this cannot in the nature of things be recovered, for in the course of time it has become so thoroughly mixed with clay and in places so covered with overburden as to make its recovery at a profit impossible. The lessons learned in Tennessee no doubt will be of value in working the brown phosphate deposits in central Kentucky.

The object, of course, in preparing phosphate for market is to remove as much of the clay, chert, and limestone as possible from it. It is not possible to remove all these impurities, especially in the case of clay and sand. There is no sharp division between the finest phosphate sand and clay and it would obviously be wasteful to carry the process of obtaining fine phosphate sand beyond the point where the cost would offset the value of the phosphate obtained. This is one of the practical considerations connected with the modern conservation of phosphate rock which perhaps has not always been given just and deserved consideration. These practical difficulties have resulted in the loss of much fine phosphate along with the silica sand and clay. Owing to the similarity of finely divided phosphate and silica sand in specific gravity, no mechanical process has been developed to effect a further saving. As the problem now stands the general development of some concentration process is required to effect a further recovery of low grade phosphate both in Tennessee and Florida, where the consumers are demanding a high grade product.

The point beyond which it is not practicable to carry preparatory treatment is not fixed and standards vary from time to time and probably at a given time among individuals or corporations. Thus in the phosphate mining industry as practiced in Tennessee in the early nineties, rock was discarded which has a high value today, and the former apparent lapses from the highest standards have in the course of time proven to be not lapses at all, but simply necessities imposed by trade conditions of the time. In other words the phosphate once discarded is now being used. The open cut or surface methods of mining brown rock as practiced in the Tennessee field, and which will be the methods employed in the Kentucky field, are peculiar in this respect and the gen-

eralizations made do not cover many other classes of mining and certainly will not apply to underground mining in general.

GRADES OF COMMERCIAL BROWN PHOSPHATE ROCK.

Most of the brown phosphate rock from the Mt. Pleasant, Tennessee, field is shipped in three grades, namely, those containing 72, 75, and 78 per cent. of calcium phosphate. The percentage of iron and aluminum oxides ("I and A") remaining in the washed product has an important bearing on the value of the rock. The usual guarantees are given below. For each per cent. in excess of the guaranty, 2 per cent. of calcium phosphate (BPL) is deducted.

Table of Guarantees Showing the Relation Between Phosphate and Iron and Alumina Content.

BPL Per cent.	$Fe_2O_3+Al_2O_3$ I and A Per cent.
70	6.5
72	5.5
75	5.0
76	4.5
78 to 80	4.0

Five to five and a half per cent. iron oxide and alumina is the usual maximum allowed and that is usually referred to as "I and A" in the trade and in commercial analyses. At one time only rock of 78 per cent. grade was shipped from the Mt. Pleasant field and rock of this grade is still known as "export rock." The guaranteed content in phosphate of lime, "bone phosphate" or "BPL" as it is commonly referred to in the trade, next fell to 75 per cent., and at the present time many of the companies are finding it difficult to ship this grade exclusively, and the life of the 75 per cent. rock is limited. Every per cent. of iron oxide and alumina less than the 5 per cent., is regarded as equivalent to an additional 2 per cent. of calcium phosphate, for it is considered that in the subsequent treatment of the phosphate in the manufacture of fertilizers the harmful effect of 1 per cent. of iron oxide and alumina offsets the good effect of 2 per cent. of calcium phosphate. If much more than 5 per

cent. of iron oxide and alumina are present the superphosphate tends to become gummy and farmers find it difficult to drill it into the land.

A few samples of Kentucky phosphate rock were selected for analysis for their content in iron, alumina, and fluorine, in addition to their content in phosphate of lime. The results of these analyses are given below. The content in iron and alumina shown are too high to come within the normal commercial requirements of the present time and indicate, as pointed out in other places in this paper, that the bulk of the Kentucky phosphate rock will no doubt have to wait for the general introduction of cheap chemical or other processes of concentration before it is able to compete with the high grade phosphate rock from the other eastern states.

Analyses of Kentucky Phosphate Rock.

(W. C. Wheeler and R. M. Kamm, Analysts.)

	$Ca_3(PO_4)_2$	Al_2O_3	Fe_2O_3	F.
No. 108B	63.87	5.29	2.09	1.38
No. 112A	60.87	4.35	3.50	1.02
No. 120	28.92	7.46	5.29	0.70
No. 126B	54.25	4.63	1.42	1.18
No. 133	24.56	10.66	6.62	0.85
No. 141	35.21	5.21	5.29	0.92
No. 143	37.56	2.50	6.05	0.95

No. 108B. Mrs. M. Murray farm, 1¼ miles southeast of Wallace, and north of Frankfort and Lexington pike.

No. 112A. Henry L. Martin estate, ¾ mile east of Wallace, and north of Frankfort-Lexington pike.

No. 120. H. L. Martin, Jr. estate, 1½ miles southeast of Midway.

No. 126B. James J. Nugent, in orchard just northeast of Wallace crossroads.

No. 133. E. L. Lillard estate, 2½ miles southeast of Midway, near South Elkhorn Creek.

No. 141. E. L. Davis estate, along the Louisville and Nashville Railroad in small sink, 1¾ miles northwest of Midway.

No. 143. Mrs. Charles Nuckols estate, 1¾ miles northwest of Midway.

PREPARATION OF PHOSPHATE ROCK FOR MARKET.

There are many stages to be considered under the head of preparation of phosphate rock for market, but they may all be subdivided into 3 major operations as

follows: (1) removal of overburden; (2) mining; and (3) milling, in which is included drying. The present methods of utilizing and thus preserving from loss the brown phosphate rock supplies, especially in the Mt. Pleasant field, are included under the above headings and therefore will be described in connection with them insofar as this can be done.

REMOVAL OF OVERBURDEN.

The overburden of the brown rock phosphate deposits in the Mt. Pleasant, Tennessee, field varies from one foot upwards. Usually it is less than 20 feet, but a thickness of 30 feet is known but is excessive in those places where mining has been in progress. The methods of removal of overburden are diverse. Under exceptional conditions the old time crude and expensive hand methods have to be resorted to, but in most places, especially where virgin ground is being opened up and where conditions are comparable with what may be expected in Kentucky, operations are conducted in the most up-to-date fashion, as the illustrations (Plates XII. to XVI.) show. Where the overburden is not very thick or hard it may be simply pried up and removed with scrapers (Plate XII.), or it may be loosened with dynamite and then removed with scrapers. A favorite method of getting rid of the overburden, used especially in ground that is being reworked, is to first "hog" or undercut it, pry it off with bars, and then scrape or carry it away. The drag line excavator (Plate XIV.) and the steam shovel (Plate XV.) are types of up-to-date machinery used to remove overburden in the Tennessee field. The hydraulic method (Plate XVI.) is also used and this would do well in the vicinity of Elkhorn Creek, Kentucky. Both the overburden and the rock beds are removed by this last named method, which is simplicity itself in action and which requires a minimum of labor in operation, namely one man to handle the hydraulic gun and two to keep the sluices clear. Of course this last named method can only be used where there is an abundant water supply.

Occasionally narrow benches are stripped by hand methods. The dirt is more or less undermined by the removal of the underlying rock and the bank caved over

into the previously mined outbench by prying with under rods from above. In the case of deposits stripped by scraper outfits, (Plate XII.) the outfits are such as are used in ordinary railroad work and consist usually of ordinary and five wheeled scrapers with a hook team extra and a plow team. This work is usually contracted at 14½ cents per cubic yard. The major portion of the stripping is now done by class 14 Bucyrus Drag Line Excavators mounting a 70-foot boom with a 1½ yard bucket. (Plate XIV.) This machine is adapted to the removal of overburden that does not average more than 15 feet in thickness. With more than this depth the pits become too narrow at the bottom.

In Hickman County, Tennessee, where the overburden averages 30 feet, a class 24 drag line machine has been used. This has a 100-foot boom and a 3½ yard bucket.

In general it cannot be said that the workability of a bed is regulated by the depth of overburden. There are other factors entering into the problem. If the phosphate bed is a very thick one, the overburden may be quite thick and still may be removed and the operation be a profitable one. On the other hand, if the bed is very thin but exceedingly high grade, it may still pay to remove what appears to be an excessively thick overburden.

COSTS OF REMOVAL OF OVERBURDEN.

The cost of operating the class 14 machines is as follows:

Cost of Operating Class 14 Bucyrus Drag Line Excavator.

	Per Shift.
1 runner ($150 per month)	$6.00
1 fireman	2.50
1 teamster	1.75
1 ground man	1.50
1 foreman	3.00
1 team (owned by company)	3.00
Coal, 2 tons at $2.40	4.80
Cable wear	5.00
Repairs, oil, and supplies	3.00
6% interest on $13,000; 250 shifts	3.20
10% depreciation	5.20
	$38.95

The above items of expense are for a machine having caterpillar traction for moving. If a timber and roller machine is used an extra ground man is required. The capacity averages 1,000 cubic yards per 10-hour shift, though often 1,300 to 1,400 yards are dug under favorable conditions. While the larger size machines average more in yardage, the operating costs also increase so that the cost per yard is nearly the same.

In those mines where hydraulic stripping is used owing to the excessive depth of overburden, or where mining conditions require it, the cost of removal amounts to about 7 cents per cubic yard. At two mines in Tennessee where this method is employed the bank is cut down by a hydraulic monitor, using a 2 or 2½ inch tip. The water pressure usually needed is 150 to 175 pounds per square inch. The water flows back from the face carrying from 10 to 20 per cent. solids into a pump well. From the sump the water and overburden are pumped to the waste ponds by an 8-inch direct connected motor driven centrifugal pump. The pump requires from 1,500 to 2,000 gallons of water per minute for full capacity with a 75 horse power motor.

METHODS OF MINING.

Much of the mining in the Mt. Pleasant, Tennessee, field has been done by hand on account of the method of occurrence of the brown rock. The steam shovel has not proved successful because it is unable to discriminate between the grades of ore mined, with the result that much clay and flint get into the product and has to be removed subsequently. The cantilever adjunct to mining which is employed at one mine in the Mt. Pleasant, Tennessee, field is unique. The hydraulic method of mining is used at two plants and has many advantages as pointed out under the preceding topic. These mechanical methods of mining and removing overburden which have cheapened operating costs, have played the major part in conserving Tennessee brown phosphate rock and without doubt will be the means whereby Kentucky rock may hope to take its place on the market.

As hydraulicking is practiced in Tennessee, the limestone horses often get in the way and have to be blasted out. But this is not difficult, owing to the loose or platy character of the phosphatic limestone associated

with the brown rock deposits. In addition to the hydraulic method which may be employed only in certain favorable locations, hand mining is also employed, especially where the ground is being reworked. Where hand mining is practiced the ore is usually screened on the spot where the miner is at work. The fine material passes through the screen and is saved and washed, and the coarse rock which is left is hauled away and dried by burning on ricks of wood in the open (see Plate XVII), thus saving rehandling in the mill. The lump rock, as mined, usually contains from 20 to 21 per cent of moisture and drying it in this way reduces the moisture to 1 per cent. or less. In certain places where mining with the hydraulic giant is not practicable or where the giant fails to get all the rock, hand mining has to be resorted to.

WORKING CUTTERS.

The term "cutters" has been explained and the fact that the phosphate rock in them was left unmined in the early days of brown rock mining has been pointed out. The development of cutters, which took place along original joint plains, varies greatly within the restricted Mt. Pleasant field and may be expected to vary much in the Kentucky field. In some places in Tennessee they are of large size and some were observed 30 to 35 feet wide and as much as 20 to 25 feet deep (Plate XVIII.), averaging probably 18 to 20 feet. In these abnormally wide and deep cutters, it is not uncommon to have small limestone horses. Some of the cutters, on the other hand, are so narrow that the phosphate rock in them can be removed only with difficulty. (Plate XIX.)

Hand methods of mining have to be employed almost exclusively to remove phosphate rock from these cutters owing to the peculiar method of its occurrence. (Plates XVIII. and XIX.) Hydraulic methods have been employed in places. Owing to the depth of the cutters the work has been done in benches of convenient height for the miners. (Plate XVIII.) The ore is picked out and shoveled from bench to bench and finally into wagons, in which it is hauled to the mills. Mining the deep cutters is usually carried on in fair weather and when the roads are good. In working over virgin ground at the present time the rock in the cutters is readily and cheaply obtained by

the cantilever method. (Plate XIII.) The material from the shallow cutters is picked out and screened on the tines of a phosphate fork or on a small, movable, 1-inch mesh screen. The coarse rock is dried or burned on ricks of wood (Plate XVII.), and the muck is taken to the mill where it is washed. The old cutters containing phosphate rock are located by hand prospecting with a long sharp steel rod.

THE COST OF MINING PHOSPHATE ROCK.

The cost of mining phosphate rock depends on several factors, chief among which is the depth and expense connected with the removal of the overburden. It will be of interest to note here average costs in the most important phosphate producing states. In South Carolina during the past ten years, as much as 22 feet of overburden have been profitably removed and river rock has been dredged from a depth of 52 feet, including a cover of 16 feet of sand and muck. In Florida, where a higher grade rock is produced, it is profitable to mine rock having an overburden of greater depth than 20 feet—the average maximum in South Carolina. According to data furnished by various companies to the Federal Trade Commission* the cost of mining Florida land pebble, including washing, drying, etc., ranges from about $1.65 to $2.50 per gross ton, not including amortization of investment or royalties in case the mining is done on that basis. The cost of mining Tennessee brown rock ranges from about $2.75 to $3.14 per gross ton and these are the figures of greatest interest in connection with the Kentucky field. The cost of mining rock in South Carolina is considerably higher. The following figures were taken from the average costs of a Tennessee mine during six months of good mining weather:†

	Per ton cents.
Mining	$0.64
Transportation and team expense	0.23
Washing	0.46
Drying	0.47
Shipping and track expense	0.09
Total per long ton of dry rock	$1.89

*Rept. on the fertilizer industry, 1916, p. 101.
†Barr, James A. Tenn. Phosphate Products. Bull. No. 93, Am. Inst. Min. Engrs., Sept., 1914, p. 2410.

The work of mining is chiefly done by contract, the price being 25 cents per tram when one handling only is required. Where two casts are required 35 to 40 cents per tram is paid. The miners keep the track up to the mining face.

WASHING AND DRYING.

The washing processes whereby the mined brown phosphate rock is freed from clay, chert, and limestone are elaborate and the mills in which the work is done are for the most part large and modern. These modern washing plants which have done so much to make the mining of low grade brown rock profitable, and which, therefore, are playing such an important role in the conservation of this class of phosphate rock, have practically all been installed during the past 10 or 15 years. The principles of the washing process are identical throughout but the details of manipulation differ at different plants. The phosphate rock as mined is brought to the washer either in wagons or by tram. Where hydraulic mining is practiced it goes to the plant through a flume. The material mixed with water is delivered into a hopper at the top of the mill and the subsequent operations for the most part are conducted by gravity. From the hopper the rock passes through a toothed revolving crusher and then into log washers. From the washers it passes to a cylindrical or conical screen with circular perforations. The coarse or lump rock which fails to pass through the screen passes on to a picking belt where limestone and chert fragments and clay balls are removed. The material then goes to the wet storage sheds or piles to be later dried. The fine material may go through a settler or clarifier provided with riffles, or through several settling tanks in succession in which the sand settles out. The clay and sand not caught in the process goes to the waste ponds. The above description briefly outlines the fundamentals of the washing process as carried out at most of the plants handling brown rock phosphate in the Mt. Pleasant, Tennessee, field, but, of course, as has been mentioned, details are widely divergent.

The clay and the phosphate sand which pass to the waste ponds are of great interest in the problem of conservation. When the material reaches the waste pond

the coarse sand settles out first and naturally nearest the end of the waste pipe or flume. This material is the highest in calcium prosphate. It is planned to work material of this character at one of the plants near Mt. Pleasant, and already at another the old tailing dumps are being worked. At this plant much attention has been paid to the process of separating the clay and phosphate sand. There is a washer at this particlar plant which differs from any other in this field and is most throuogh in its action. The clay resulting from the action of this washer was observed in the waste pond. It has been in suspension for a long time and material taken and rubbed between the fingers appeared of almost impalpable fineness. Some of the phosphate sand from this washing process is so fine in texture that it sifts through the meshes of the sacks in which it is shipped. It has been suggested that material from such waste ponds might be used in its present form on farm lands, but this has been found impracticable as it will not bear the cost of transportation, but the high phosphate content in certain of the samples collected from such waste ponds is noteworthy.

Drying is accomplished in two very different ways which are representative of the old and new methods employed in the Tennessee brown phosphate field. At nearly all the large plants modern rotating cylindrical dryers, similar to rotary cement kilns, are in use, but the rock is fed both at the hot and cold ends. It would seem that the latter method would be the more efficient. There is generally some special cause when the old fashioned method of drying on wood ricks is employed and where it is in use it generally saves extra additional handling or haulage. Drying generally reduces the moisture present from 20 or 21 per cent to 1 or 2 per cent.

CONSERVATION OF FINES.

In drying phosphate rock large quantities of material in finely divided form is lost by being carried out of the flue, owing to the powerful drafts employed, especially in the modern types of dryers. At many of the plants steps have been taken to save this material. This is accomplished by means of bends in the flue, or by

hoods or baffles. The analysis of the fine material caught and saved at some of the plants indicates that it is well worth saving.

THE PHOSPHATE INDUSTRY AT WALLACE, KENTUCKY.

The phosphate deposits on certain farms near Wallace at the time of the writer's visit were under lease by the Central Kentucky Phosphate Company. Since then (June, 1915) they have changed hands and are now being worked by the United Phosphate and Chemical Company which, it is understood, is a subsidiary of the Charleston, South Carolina, Mining and Manufacturing Company. Since work started at Wallace some few years ago it has been carried on intermittently and there have been many shut downs lasting for short or long periods. The total tonnage removed from the Wallace workings has been small and in all has not amounted to more than a few thousand tons (1,500 to 2,000 tons). Since the writer visited the plant in June, 1915, it has been added to considerably, and it is expected to resume operations on a larger scale than ever early in 1917. In the early part of this year, the Hawkins farm, which adjoins that on which the old workings are located, has been acquired and it is planned to work out to the Steele and Murray farms which are nearby and under lease.

The overburden at the Wallace workings varies from a fraction of a foot to 5 or 6 feet in thickness. It occasionally reaches 10 feet. Due to its thinness, it may be removed directly by scrapers, after it is first plowed up or loosened with pick and shovel.

After the removel of the overburden, the phosphate rock is usually removed with pick and shovel, loaded by hand on to wagons, and hauled to the mill. The deposit at Wallace normally ranges from 3 to 5 feet in thickness. The extremes of thickness are 1 foot and 10 feet. When the ore is of the maximum thickness it proved too costly to remove it all according to the methods employed in this field.

Electric power is used at the mill. The ore at the mill is shoveled on to a belt which feeds it to a revolving cylindrical dryer 40 feet long and 5 feet in diameter. This is fed with coal which is burned under a forced

draft. The ore in the dryer travels forward and downward to the hotter end. From the dryer it falls into a pit through which passes an endless bucket conveyor, which carries it to a horizontal screen conveyor. The latter in turn transfers it to a hopper through which it falls on to burrs or grinders. Before falling on to the burrs, the lump rock is screened, only those fragments which are ½ inch or less in diameter going into the crushers. The screen is a cylindrical affair containing ½ inch holes. All the lump rock passes over the screen to a conveyor and goes to a loading bin to be wheeled on to cars later, or it may be chuted directly on to cars.

The material which has passed through the crushers is further ground to phosphate flour and conveyed by elevators to its own bin. The ground rock is bagged in paper bags of 100 or 200 pounds each, and shipped in this form for direct application to the soil.

The old company whose methods are described above has a spur built to its plant from a short branch line of the Southern Railway running between Georgetown and Versailles, Kentucky. The new company proposes to grade tracks to those farms it proposes to work.

TRANSPORTATION FACILITIES.

The Wallace area and the area to the west of Midway are admirably located with respect to railroad transportation. The main line of the Louisville and Nashville Railway between Lexington and Louisville, passes through Midway and the phosphate area to the west between Midway and Spring Station. A branch of the Southern Railway between Versailles and Georgetown passes through the heart of the Wallace area, and the topography or lay of the land about Wallace is such that spur tracks may be built where needed at a minimum of expense. The railroad requirements, therefore, could hardly be improved upon.

The Kentucky deposits are also well located from the viewpoint of distribution to the north in Ohio, and northwest in Indiana and Illinois, where more and more raw ground rock is coming into use. The freight rates from Midway to Louisville, Cincinnati, and Cleveland are in each case less than from Mt. Pleasant, Wales Station, and Nashville, Tennessee, and this difference in

freight rates may compensate for a lesser content in calcium phosphate in the Kentucky rock, and where composition and other conditions are equal, result in a demand for the latter.

The following table is of interest in this connection:

Freight Rates From Mines in Kentucky and Tennessee to Important Near By Markets.

Destination.	Location of Mines.	Freight Rates.
Cincinnati, Ohio	Midway, Ky.	$1.60
	Mount Pleasant, Tenn.	2.50
	Wales Station, Tenn.	2.50
	Nashville, Tenn.	1.80
Louisville, Ky.	Midway, Ky.	1.60
	Mount Pleasant, Tenn.	2.25
	Wales Station, Tenn.	2.25
	Nashville, Tenn.	1.55
Cleveland, Ohio	Midway, Ky.	3.22
	Mount Pleasant, Tenn.	3.80
	Wales Station, Tenn.	3.80
	Nashville, Tenn.	3.12

RAW ROCK PHOSPHATE.

Finely ground rock phosphate, sometimes called "floats," is used to a considerable extent by farmers, particularly in the middle west, as a source of phosphorus. It is often lower in phosphate of lime and consequently higher in iron and alumina than rock used for acidulating purposes. In the raw condition, the iron and alumina, if in the form of phosphate, are advantageous according to certain scientists who have experimented with these phosphates, because they have been found to supply a favorable medium for the germination of seeds. Floats are applied directly in turning under crops, or are mixed with barnyard manure on the theory that the phosphoric acid is liberated and rendered available by the action of the weak organic acids generated during the decomposition of the manure.

The future of the Kentucky phosphate field as a source of raw ground rock ought to be good. The use

of this material in the states to the north and west is becoming increasingly popular. The advantages in freight rates as compared with the nearest competing field in similar rock, the quality and other factors being equal, is important, as is also the additional fact that a high content in iron and alumina in the raw rock is not considered such a drawback as in rock which is acidulated in making acid phosphate for mixed fertilizers. Floats have been shipped in the past from the Kentucky field when operations have been in progress in that locality.

PHOSPHATIC LIMESTONE AS A SOURCE OF PHOSPHATE.

Directly below the phosphate rock horizon occurs the phosphatic limestone from which the brown rock itself has been derived. This is often platy in structure, the plates of highly phosphatic material alternating with the nearly pure calcareous layers. This platy or laminated structure is original and throws light on the occurrences of the brown rock itself which also occurs in plates separated by layers of muck, clay, and sand, the former corresponding to original layers of phosphatic limestone, and the latter to the intermediate clay and less phosphatic limestone layers. There must be an enormous tonnage of this phosphatic limestone scattered throughout the phosphatic rock area of the blue grass region of Kentucky. A long period of time must elapse before any attention will be given to this comparatively low grade material as a source of phosphate, but it would be hazardous to say that this will never be done. Analyses of these limestones, some of which are in a leached and some in a partially leached condition, occurring in horses between cutters contained as much as 70 per cent. calcium phosphate, and Foerste reports unaltered phosphatic limestone in the Woodburn member at Versailles containing 55.5 per cent. calcium phosphate.* In Tennessee some of this phosphatic limestone whose analyses the writer is acquainted with averages more than 42 per cent. in calcium phosphate. The carbonate and the phosphate of calcium mixture in this material has considerable value as a fertilizer when ap-

*Ky. Geol. Survey, Series IV., Vol. I, Part I, 1913, p. 386.

plied directly to the land in finely pulverized form, and although it is difficult to predict how or when such material will be utilized, it seems fairly certain that it will prove of value at some future time.

THE FUTURE OF LOW OR INTERMEDIATE GRADE PHOSPHATE ROCK.

General Remarks.

There is associated with all phosphate rock deposits considerable rock which is not up to present commercial requirements in content of calcium phosphate. There is also being produced in connection with the preparation of commercial phosphate rock for market a great deal of low grade material. To bring these classes of material up to commercial grade, that is to a grade containing 70 per cent. or more calcium phosphate, various chemical methods have been used. The time will undoubtedly come when these chemical methods will find much more extended application than at present, and when this time arrives it will result in the utilization of a great deal of phosphate rock now consigned to waste ponds and dumps, and also much which will not bear the present cost of mining. Such methods are of more than ordinary interest in connection with the Kentucky field. The large quantities of by-product sulphuric acid which will become available in increasing quantity as time goes on as the result of the elimination of the smelter smoke nuisance, is an important element in the situation. Immense quantities of such acid has in the past been available in southeastern Tennessee, and is potentially available at the smelters in the vicinity of our western phosphate field. Indeed the chemical method of concentrating phosphate and thus enabling it to be transported long distances may well be worked out in connection with the high grade rock that the western phosphate field is able to produce, and it will also be the means of conserving the enormous quantity of low grade phosphate rock in the Kentucky and other eastern fields.

CHEMISTRY OF PROCESS.

Phosphate rock is marketed now as such, and in the form of acid phosphate, including in the latter term ordinary super and double-acid phosphate, the latter containing two to three times as much soluble phosphoric acid as ordinary super-phosphate.

Before the discovery of the extensive high grade deposits of phosphate rock in this country and abroad, the manufacture of the concentrated grades of soluble phosphate was in fairly common practice. The large supplies of high grade phosphate rock have rendered this unnecessary, though in Europe and in parts of the United States this practice is reported to be still in use.

The basic reaction involved in the preparation of soluble acid phosphate takes place when ordinary rock phosphate $Ca_3(PO_4)_2$ is treated with sulphuric acid. In simple form, the reaction that takes place may be represented thus:

(1) $Ca_3(PO_4)_2+3H_2SO_4=2H_3PO_4+3CaSO_4$.

(2) $4H_3PO_4+Ca_3(PO_4)_2=3CaH_4(PO_4)_2$.

Reduced to one equation, this is as follows:

$Ca_3(PO_4)_2+2H_2SO_4=CaH_4(PO_4)_2+2CaSO_4$.

In the presence of water, which has been omitted from the above equations in order to simplify them, the calcium sulphate would be changed into gypsum by abstracting water from the mass. The last reaction is the one desired by the manufacturers.

To utilize low grade rock and tailings, and to make concentrated phosphatic fertilizers, the phosphoric acid produced by the first reaction is evaporated in pans until it contains about 45 per cent. phosphoric anhydride. It is then treated with a fresh supply of phosphate rock, when the following reaction ensues:

$Ca_3(PO_4)_2+4H_3PO_4=3CaH_4(PO_4)_2$.

It will be observed, therefore, that ordinary superphosphate is largely a mixture of soluble calcium phosphate and gypsum, while the double acid phosphate contains little or no calcium sulphate, or dehydrater, and thus has to be artificially dried. Either the phosphoric acid itself, the double phosphate, or such compounds as potassium or ammonium phosphate, might be shipped from our western field, since they are highly concentrated products.

EXPERIMENTAL WORK IN THE WEST.

Chemical Methods.

With reference to the results accomplished to date in the west toward the production of a high grade phosphate product which may be shipped to eastern markets, the following is of interest:*

The first effort, having in view the production of a high grade phosphate product which would stand the cost of shipment to eastern markets, was instituted by the Mountain Copper Company, at Martinez, California. This company for many years has been producing and marketing locally a super-phosphate, and some years ago endeavored to produce a high grade product. The possibility of making a high grade phosphate product has also been considered and discussed by the technical staff of the American Smelting and Refining Company in connection with their acid plant at Garfield, Utah.

At Anaconda during the past two years a consistent and elaborate investigation with a high grade phosphate product in view has been made. The desire has been to obtain an outlet for the waste sulphur dioxide gas of the smelter through the production and utilization of sulphuric acid. The investigation was started on a small scale in the laboratory, and is now advanced to the point where a unit of 500 pounds of phosphate rock per day capacity is being operated. Stated briefly, the results obtained up to the present time are as follows:

Decomposition of the phosphate rock containing from 30 to 33 per cent. P_2O_5 has been effected by grinding with dilute sulphuric acid, agitation with acid, or treatment with acid in a "den," as in the manufacture of ordinary super-phosphate. The best recoveries have been made by using the "den" decomposition followed by leaching.

The rock is first treated with nearly the theoretical amount of sulphuric acid in a "den" to take care of the lime. The mixture "sets" after a few minutes stirring and usually is allowed to stand covered for 16 hours at about 40° C. The mixture is then leached with solutions from previous leachings containing about 6 per cent. sulphuric acid. The material filters quite satisfactorily

*Communicated by A. E. Wells of the Mine Experiment Station of the Bureau of Mines at Salt Lake City, Utah.

when the sulphuric acid content of the leaching solution is properly maintained, and the resulting solution may contain as high as 20 per cent. P_2O_5. The extraction is about 90 per cent of the P_2O_5 in the rock.

In one line of investigation the solutions were evaporated to about 45 per cent. P_2O_5, at which concentration some calcium sulphate was deposited. This phosphoric acid solution was then added to more phosphate rock, the amount of rock used being about 80 per cent. of that theoretically required to combine with the phosphoric acid, according to the reaction: $Ca_3(PO_4)_2+4H_3PO_4=3CaH_4(PO_4)_2$. The mixture was allowed to stand for several hours and then dried. A dry ,grindable product containing about 50 per cent. available P_2O_5 was obtained.

Another line of investigation has aimed to produce a high grade phosphoric acid liquor or even glacial phosphoric acid. The solutions from the leaching mentioned above have been evaporated on steam baths to the point where they contain 62 per cent. P_2O_5. As stated above, calcium sulphate begins to deposit when the concentration reaches about 40 per cent. P_2O_5, and continues to deposit as the concentration increases. In the laboratory all evaporations were effected in lead or glass, as the dilute solutions corroded iron rapidly. In some long-time evaporations, a glacial acid, a mixture of pyro and meta phosphoric acid resulted, containing as much as 70 to 80 per cent. P_2O_5.

Experiments are in progress in connection with the work now being conducted on the 500-pound unit, to determine the possibility of evaporation in a tower such as is used in sulphuric acid concentration. At the Bureau of Mines experiment station in Salt Lake City, tests are in progress to determine whether the solution can be evaporated to a dry P_2O_5 powder by spraying the dilute or partially evaporated solutions into a stream of hot gases and precipitating the dehydrated acid by electrical precipitation methods. The evaporation problem still remains the most serious one in the production of a high grade phosphoric acid liquor or of glacial phosphoric acid. Due to the hygroscopic properties of the glacial acid, and the necessity of shipping it in sealed, iron containers, it is believed that it will be most feasible to

prepare a 60 to 65 per cent. P_2O_5 solution to be shipped in tank cars.

The possibility of substituting this phosphoric acid solution for sulphuric acid in the recovery of ammonia at the by-product coke plants with the production of ammonium phosphate, is being investigated. No data from this investigation are yet available.

Though it is true that the grade of rock on which work has been done contains fairly high percentages of phosphoric acid, there is in Montana, within a distance of 30 miles of the Anaconda smelter, large deposits of phosphate rock which will average only about 23 per cent. P_2O_5, and in time it is likely that these deposits will be of considerable value. At the present time the phosphoric acid solutions from this grade of rock contain so much iron and alumina that it has been felt that it would be much better to work out the problem with the use of the higher grade rock, of which a great deal is present and can be easily mined in southern Idaho and northern Utah.

ELECTRICAL METHODS.

An interesting and recent development in the utilization of low grade phosphate rock is in the production of phosphoric acid and its derivatives, ammonium phosphate and double super-phosphate, by utilization of the electric furnace. Sulphuric acid is here replaced by silica, coke, and electric energy, and with very cheap electric energy, the resulting product may be produced considerably cheaper and in a much more available form than by the present methods. The fertilizers produced with the aid of electric energy, fixed nitrogen and available phosphoric acid, go hand in hand with cheap water power.

Ross, Carothers, and Merz* have recently summarized the results of certain experiments in the use of the Cottrell precipitator in recovering phosphoric acid evolved in the volatilization method of treating phosphate rock by ignition with coke and silica in an electric furnace. "A current of air which was passed over the

*Ross, W. H., Carothers, J. N., Merz, A. R. The use of the Cottrell precipitator in recovering the phosphoric acid evolved in the volatilization method of treating phosphate rock. Journal of Industrial and Engineering Chemistry, Vol. IX., No. 1, January 1, 1917, pp. 26-31.

charge in the furnace served the double purpose of oxidizing the fumes of phosphorus to phosphorus pentoxide and of carrying the latter to the precipitator. In one series of experiments the fumes from the furnace before entering the precipitator were passed through a tower provided with baffle plates which had the effect of cooling down the gases to about ordinary temperature. In a second series of experiments the tower was cut out and the fumes passed almost directly into the precipitator at a temperature above 100° C. In each case the phosphorus pentoxide, which takes up water from the current of air passing through the furnace and also from the moisture driven off from the charge, is precipitated in the form of a solution of phosphoric acid. When the precipitation is made at temperatures about 100°, or above, the concentration of the acid is greater than that collected at a lower temperature, but by reducing the flow of air through the furnace, acid of high concentration may also be obtained with low temperature precipitation.

"The advanutages of this method of collecting the phosphoric acid over the scrubbing tower method now in use are as follows:

"1. The equipment required is simple in construction and automatic in operation.

"2. The simplicity of the construction of the precipitating pipes decreases the difficulties arising from the corrosive action of the phosphoric and hydrofluoric acids evolved from the phosphate rock.

"3. In this way there may be recovered phosphoric acid of a high degree of purity suited for direct use without further purification in those industries where a relatively pure acid is required.

"4. A more concentrated acid can be obtained in this way than is possible to prepare directly by any other commercial process, and when this acid is used in the preparation of concentrated fertilizers, such as mono-ammonium phosphate, a dry product may be obtained directly without the necessity of evaporating solutions, or of drying the resultant product.

"This is the first time that the Cottrell precipitator has been used for the precipitation of a product which

has been purposely volatilized with a view to its recovery in this way."

The fertilizer division of the Bureau of Soils has given considerable attention to the preparation of concentrated fertilizers and a paper recently prepared by William H. Ross and Albert R. Merz* gives a general account of some methods which may prove to be applicable in their preparation. The one which concerns this paper more especially relates to the preparation of phosphoric acid together with potassium and ammonium phosphates.

Practically the entire output of fertilizers in the United States is consumed east of the Mississippi river, and more than four-fifths of this consumption is in the states bordering on the Atlantic Ocean and the Gulf of Mexico. Our natural resources in phosphate rock, however, occur in overwhelming preponderance in the far west.†

"A serious problem presents itself in bringing these raw materials or products derived from them to the region of consumption, as the distances are great and the only means of transportation available, that by rail, is expensive. A partial solution of this problem is found in the production of concentrated fertilizers, whereby the ratio of the cost of transportation to the value of the material shipped is considerably diminished.

"The simplest of these commercial fertilizers in chemical constitution is phosphoric acid. The processes which have been used commercially for the preparation of this acid may be conveniently divided into two classes, as follows: (1) Processes which involve treatment of the rock with a mineral acid such as sulphuric acid; and (2) processes in which the phosphorus is evolved from the rock by ignition with silica and coke and its subsequent conversion into phosphoric acid through oxidation and absorption of the anhydride in some form of scrubbing tower. With the volatilization method it has been found possible to prepare an acid of greater concentration than it is possible to obtain directly in any process of the first group, but even in this process when the

*Ross, W. H., and Merz, A. R. The preparation of concentrated fertilizers: The American Fertilizer, Vol. 45, No. 8, October 14, 1916, pp. 32-35.

†See paper by Phalen, W. C. The conservation of phosphate rock in the United States: Trans. Am. Inst. Min. Engrs., Bull. 119, November, 1916, pp. 1901-1934.

scrubbing tower method of recovering the phosphoric acid is used it is impractical to obtain an acid of greater strength than about 50 per cent. phosphorus pentoxide and evaporation must be resorted to for further concentration. However, if the scrubbing tower be replaced by a Cottrell precipitator, no difficulty is found in securing phosphoric acid which contains upward of 95.0 per cent. phosphoric acid. A high grade phosphate rock of 75 per cent tricalcium phosphate has 34.4 per cent. P_2O_5, whereas a 95.0 per cent. phosphoric acid solution contains 68.8 per cent P_2O_5. Therefore we have produced a fertilizer material twice as concentrated as high grade rock or over four times as concentrated as 16 per cent. super-phosphate and having all the P_2O_5 in the so-called available form. It may be interesting to note that this is the first time that the Cottrell precipitator has been used for the precipitation of a product which has been purposely volatilized with a view to its recovery in this way. A detailed description of the experiments conducted with the precipitator and the advantages of its application are given in the paper referred to above.

"The phosphoric acid which is produced by this procedure may be shipped directly in suitable containers to the region of fertilizer consumption, there to be used in the preparation of mixed fertilizers. This is now actually being considered by a western concern which contemplates shipping phosphoric acid that has been extracted from western phosphates by the sulphuric acid method and concentrated by evaporation."

The studies made by Ross and Merz also include the direct preparation of salts in which the phosphoric acid was combined with a fertilizer base such as potassium and ammonium to produce the corresponding potassium (K_3PO_4) and ammonium phosphate ($(NH_4)_3PO_4$). Methods of producing a concentrated fertilizer containing all three fertilizer elements, that is nitrogen, potash, and phosphorus, are also outlined.

THE FUTURE OUTLOOK FOR THE KENTUCKY PHOSPHATE FIELD.

From what has been stated with reference to the Kentucky phosphate field, it is evident that rock of high grade has been found in different places in the blue grass

region of central Kentucky, and without doubt many more workable deposits will be found as the entire region is systematically and carefully prospected according to the methods usually employed in this work and outlined in this paper.

A somewhat restricted district in the vicinity of Wallace, a few miles south, southeast and southwest of Midway, Woodford County, is the only one of prominence within which phosphate rock is found to occur to any great extent. Between Midway and Spring Station, along the Louisville and Nashville Railroad, and on certain farms to the north of the railroad, is another area where phosphate rock has been found in some quantity. The limits of these areas have not been very accurately determined, but enough drilling has been done to indicate that very important deposits of phosphate rock should be expected to be found locally. When it is remembered that brown rock phosphate may run from 600 to 1,000 tons per acre per foot of thickness, small areas may prove of great importance if the phosphate deposits in them are thick enough and of good quality.

Outside of the Wallace area and that to the west of Midway, phosphate rock is known to occur in and around Lexington, Fayette County, in the vicinity of Georgetown, Scott County, near the Forks of Elkhorn, Franklin county, near Versailles, Woodford County, and near Pine Grove Station, Clark County.

The material collected from the drillings made in this field shows great variation in content of calcium phosphate, and the sections themselves also show great irregularity in the thickness of the phosphate bed. In the Wallace district, of the total number of analyses made of materials collected from drillings, about one-third showed a content of 50 per cent. or more of calcium phosphate. Less than 10 per cent. of the total showed a content between 60 and 70 per cent., and but 5 per cent. of the total showed more than 70 per cent. The latter material was, for the most part, collected from well exposed sections in the old workings of the Central Kentucky Phosphate Company, near Wallace. The remaining 65 per cent. contained less than 50 per cent. calcium phosphate, and the great bulk of the material carried from 30 to 50 per cent. The other localities in which prospect-

ing was carried on showed approximately similar results.

Occasional occurrences of lump rock were found in this area, containing more than 80 per cent. calcium phosphate, and although rock in workable quantity may be found running up to and above present commercial requirements, that is, containing 70 per cent. and more calcium phosphate, it is quite safe to affirm that the bulk of Kentucky rock will be found to contain less than 70 per cent. BPL. This means that in the most promising areas the rock will have to be carefully washed and cheaply worked by the most modern, labor saving devices, to bring it up to present commercial standards so that it will be able to compete in the open market with Tennessee rock. Without doubt, much of the Kentucky rock of low or intermediate grade must wait for cheap chemical or electrical processes of concentration. Some of the very latest developments in these processes are described in this paper.

The Kentucky phosphate field is practically a virgin field. From its study and a comparison of it with the Tennessee field, it is felt that local conditions are similar and the problem of working the Kentucky phosphate deposits must be along much the same lines as in Tennessee. For this reason, brief descriptions of the technology of the mining and preparation of phosphate rock for market as practiced in the Mt. Pleasant district of Tennessee are given.

The advantages of the Kentucky field with respect to transportation rates to markets in the north and west are pointed out. Though the Kentucky field has an advantage in freight rates to important fertilizer markets in Ohio, Indiana and Illinois, this has not led to the establishment of any important industry in the State thus far. The Tennessee field, the pioneer, has enjoyed the advantages usually accruing to the first in the field. The Tennessee rock, on the average, is a higher grade rock than the Kentucky, which gives the former certain advantages, until effective concentration methods, either mechanical, chemical, or both, are introduced in the Kentucky field.

The lands on which the Kentucky rock phosphate has been found are very fertile, in fact are the most

fertile in the blue grass region. Consequently they possess high values for farm and grazing purposes, and are worth at least $200 per acre for these purposes alone. The extent to which the Kentucky field will be developed depends not only on what may underlie the land, but on the attitude assumed by the farmers who own it. Whether it is considered more valuable for farming purposes than for the phosphate deposits which underlie it in places, remains to be seen, assuming, of course, that exact knowledge with regard to its mineral wealth becomes better known as time goes on. It is certain that after mining operations have been conducted it will cost much to bring the land into condition for farming, if this can be done at all. In this connection, however, it is of interest to point out that in Tennessee, where hydraulic mining is practiced in one locality, the rock is mined out in a small area and the overburden from that next to it is washed into the area which has been mined out. The resultant topography is level and may be farmed over again, a most important consideration where the land is as valuable as in the Kentucky Blue Grass region. According to this method of removing overburden, the land is conserved for farming purposes for future generations and greatly improved at the same time, for a part of the phosphate rock and sand formerly below the subsoil is thoroughly incorporated into the top soil, and the fertilizer value of the phosphate rock thus rendered available in time.

Many extensive deposits of low grade Kentucky rock may be expected to become profitable in the future, as methods for their practical utilization are solved, and as the supply of high grade rock in other eastern states shall have become exhausted.

BIBLIOGRAPHY OF PUBLICATIONS RELATING TO PHOSPHATE ROCK.

Barr, James A., Tennessee phosphate practice: Trans. Am. Inst. Min. Engrs., Bull. 93, Sept., 1914, pp. 2397-2413.

——— The use of low grade phosphate: Trans. Am. Inst. Min. Engrs., Bull. 110, Feb., 1916, pp. 243-245.

Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey, Bull. 430, pp. 536-551, 1910.

——— A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 452-481, 1911.

Chatard, T. M., Phosphate chemistry as it concerns the miner: Trans. Am. Inst. Min. Engrs., Vol. XXI., pp. 160-175, 1893.

Darton, N. H., and Siebenthal, C. E., Geology and mineral resources of the Laramie Basin, Wyo.; a preliminary report: U. S. Geol. Survey Bull. 364, pp. 81, 1909.

Eckel, E. C., Recently discovered extension of Tennessee white-phosphate field: U. S. Geol. Survey Mineral Resources, 1900 pp. 812-813, 1901.

——— Utilization of iron and steel slags: U. S. Geol. Survey Bull. 213, pp. 221-231, 1903.

——— The white phosphates of Decatur County, Tenn.: U. S. Geol. Survey Bull. 213, pp. 424-425, 1903.

Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., Vol. 21, pp. 196-231, 1893.

Foerste, A. E., The phosphate deposits in the upper Trenton limestones of Central Kentucky: Ky. Geol. Survey, Series IV., Vol. I., Part I., 1913, pp. 391-439.

Gale, H. S., Rock phosphate near Melrose, Mont.: U. S. Geol. Survey Bull. 470, pp. 440-451, 1911.

Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457-535, 1910.

Gardner, James H., Rock phosphate in Kentucky: Mines and Minerals, November, 1912, pp. 207-209.

Girty, G. H., The fauna of the phosphate beds of the Park City formation of Idaho, Utah, and Wyoming: U. S. Geol. Survey Bull. 436, 82 pp., 1910.

Hayes, C. W., The Tennessee phosphates: U. S. Geol. Survey, Sixteenth Ann. Rept., pt. 4, pp. 610-630, 1895; Seventeenth Ann. Rept., pt. 2, pp. 519-550, 1896.

——— The white phosphates of Tennessee: Am. Inst. Min. Eng. Trans., Vol. 25, pp. 19-28, 1896.

——— A brief reconnaissance of the Tennessee phosphate field: U. S. Geol. Survey, Twentieth Ann. Rept., pt. 6, continued, pp. 633-638, 1899.

——— The geological relations of the Tennessee brown phosphates: Science, Vol. 12, p. 1005, 1900.

——— Tennessee white phosphate: U. S. Geol. Survey, Twenty-first Ann. Rept., pt. 3, pp. 473-485, 1901.

——— Origin and extent of the Tennessee white phosphates: U. S. Geol. Survey Bull. 213, pp. 418-423, 1903.

Hook, J. S., The brown and blue phosphate rock deposits of South Central Tennessee: The Resources of Tennessee, Vol. IV., No. 2, April, 1914, pp. 51-83.

——— The white phosphates of Tennessee: The Resources of Tennessee, Vol. V., No. 1, January, 1915, pp. 23-33.

Ihlseng, M. C., A phosphate prospect in Pennsylvania: U. S. Geol. Survey, Seventeenth Ann. Rept., pt. 3, continued, pp. 955-957, 1896.

Matson, G. C., The phosphate deposits of Florida: U. S. Geol. Survey Bull. 604, pp. 101, 17 pls., 1915.

Mansfield, G. R., A reconnaissance for phosphate in the Salt River Range, Wyo.: U. S. Geol. Survey Bull. 620, pp. 331-349, 1915.

Maynard, T. Poole, White rock phosphates of Decatur County, Tennessee: The Resources of Tennessee, Vol. III., No. 3, July, 1913, pp. 161-169.

Memminger, C. G., Commercial development of the Tennessee phosphates: U. S. Geol. Survey, Sixteenth Ann. Rept., pt. 4, pp. 631-635, 1895.

Miller, A. M., The association of the gastropod genus cyclora with phosphate of lime deposits: Am. Geologist, Vol. XVII., Feb., 1896, pp. 74-76.

——— Safford on Tennessee phosphate: Am. Geologist, Feb., 1894, Vol. XIII., No. 2, pp. 107-109.

Moses, O. A., The phosphate deposits of South Carolina: U. S. Geol. Survey Mineral Resources, 1882, pp. 504-521, 1883.

Pardee, J. T., Some further discoveries of rock phosphate in Montana: U. S. Geol. Survey Bull. 530, pp. 285-291, 1913.

Penrose, R. A. F., Nature and origin of deposits of phosphate lime: U. S. Geol. Survey Bull. 46, 143 pp., 1888.

Phalen, W. C., Phosphate rock: U. S. Geol. Survey Mineral Resources, 1912, pt. 2, pp. 855-876, 1913; idem., 1913, pt. 2, pp. 273-289, 1914; idem., 1914, pt. 2, pp. 41-56, 1915.

——— The conservation of phosphate rock in the United States: Trans. Am. Inst. Min. Engrs. Bull., No. 119, Nov., 1916, pp. 1901-1913.

Purdue, A. H., Developed phosphate deposits of northern Arkansas: U. S. Geol. Survey Bull. 315, pp. 463-473, 1907.

Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: U. S. Geol. Survey Bull. 470, pp. 371-439, 1911.

Richards, R. W., and Mansfield, G. R., Geology of the phosphate deposits northeast of Georgetown, Idaho: U. S. Geol. Survey Bull. 577, 76 pp., 14 pls., 1914.

Rogers, G. S., The phosphate deposits of South Carolina: U. S. Geol. Survey Bull. 580, pp. 183-220, 1914.

Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 131-134, 1914.

Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267-281, 1913.

Smith, G. O., and others, The classification of the public lands: U. S. Geol. Survey Bull. 537, pp. 123-134, 1913.

Stone, R. W. and Bonine, C. A., The Elliston phosphate field, Montana: U. S. Geol. Survey Bull. 580, pp. 373-383, 1914.

Stose, G. W., Phosphorus ore at Mount Holly Springs, Pa.: U. S. Geol. Survey Bull. 315, pp. 474-483, 1907.

——— Phosphorus: U. S. Geol. Survey Mineral Resources, 1906, pp. 1084-1090, 1907.

——— Phosphate deposits in southwestern Virginia: U. S. Geol. Survey Bull. 540, pp. 383-396, 1914.

Stubbs, W. C., Phosphates of Alabama: U. S. Geol. Survey Mineral Resources, 1883-84, pp. 794-803, 1885.

Van Horn, F. B., The phosphate deposits of the United States: U. S. Geol. Survey Bull. 394, pp. 157-171, 1909.

——— Phosphate rock: U. S. Geol. Survey Mineral Resources, 1911, pt. 2, pp. 877-888, 1912.

Waggaman, W. H., A review of the phosphate fields of Florida: U. S. Dept. of Agriculture, Bureau of Soils, Bull. 76, 1911.

——— A report on the phosphate fields of South Carolina: Bull. of the Dept. of Agriculture, No. 18, 1913.

Waggaman, W. H., and Fry, W. H., Phosphate rock and methods proposed for its utilization as a fertilizer: U. S. Dept. of Agriculture, Bull. 312, 1915.

Weeks, F. B., Phosphate deposits in the Western United States: U. S. Geol. Survey Bull. 340, pp. 441-447, 1908.

Weeks, F. B., and Ferrier, W. F., Phosphate deposits in western United States: U. S. Geol. Survey Bull. 315, pp. 449-462, 1907.

Wilber, F. A., Greensand marls in the United States: U. S. Geol. Survey Mineral Resources, 1882, pp. 522-526, 1883.

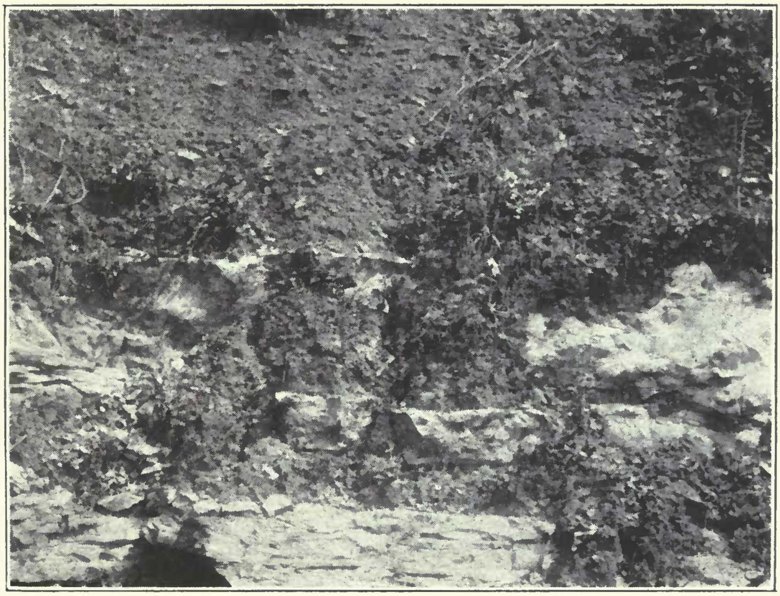

Plate I.

View of Brannon cherty limestone with upper contorted limestone layer and overlying phosphate rock debris. Cut on Queen & Crescent Route near Virginia Avenue bridge, Lexington, Ky.

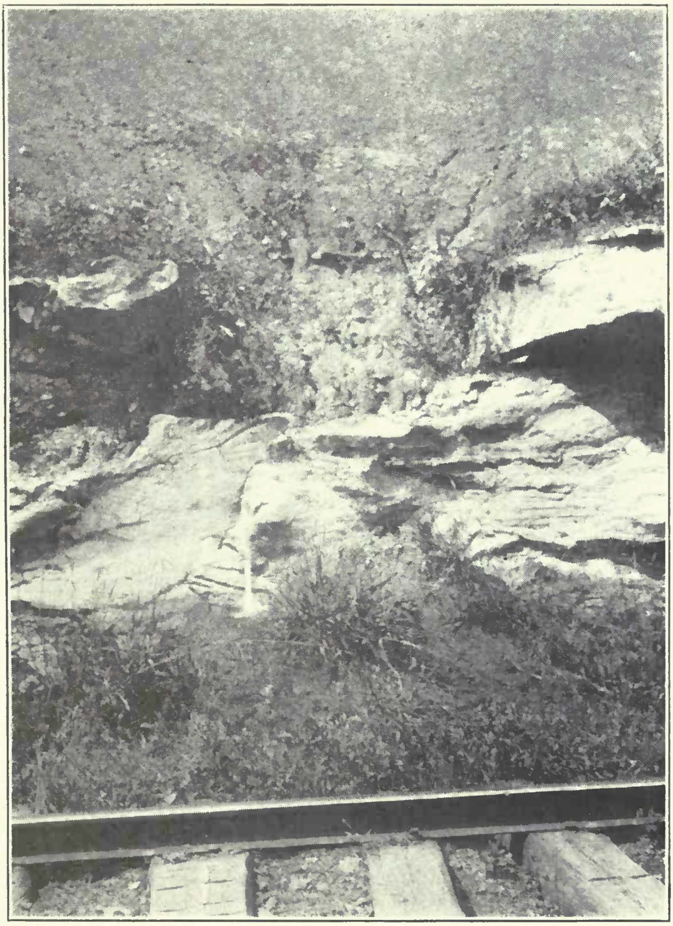

Plate II.

View showing irregular bedding in the Brannon cherty limestone near Virginia Avenue bridge, Lexington, Ky.

Plate III.

Crushed zone in limestone in the Brannon member. East side of Versailles-Frankfort pike, about 3 miles north of Versailles, Woodford County, Ky.

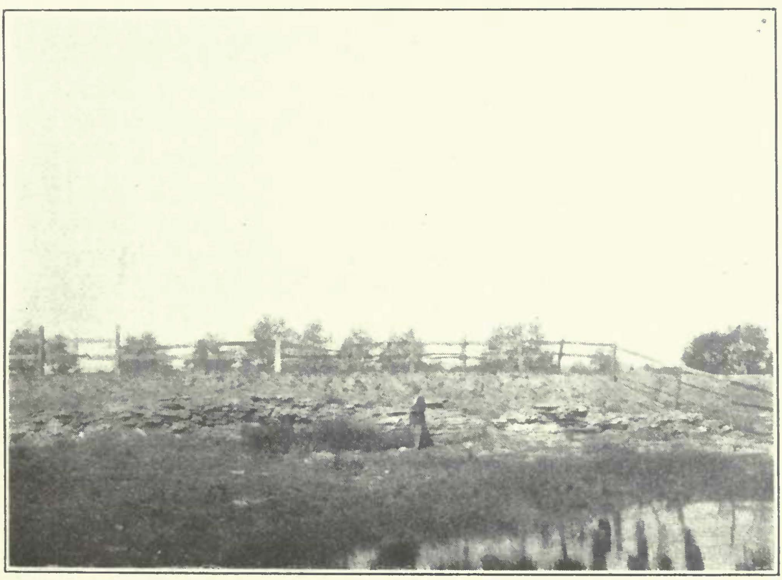

Plate IV.

Old McMeekin limestone quarry, Newtown pike, 3 miles north of Lexington, Ky. In this quarry Dr. R. Peter first noted the association of cyclora and phosphate rock.

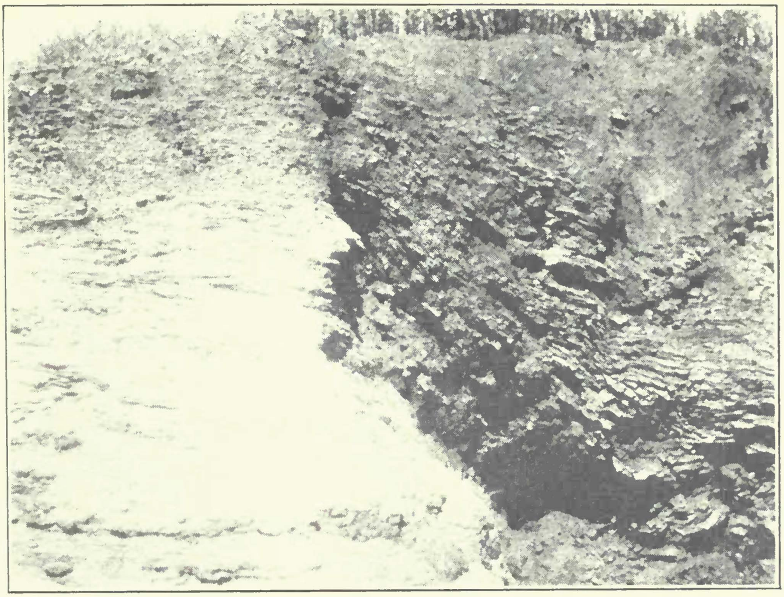

Plate V.

Arching of phosphate rock over limestone horse. Note the banding in the phosphate rock and also in the limestone. United Phosphate and Chemical Co., near Wallace, Ky.

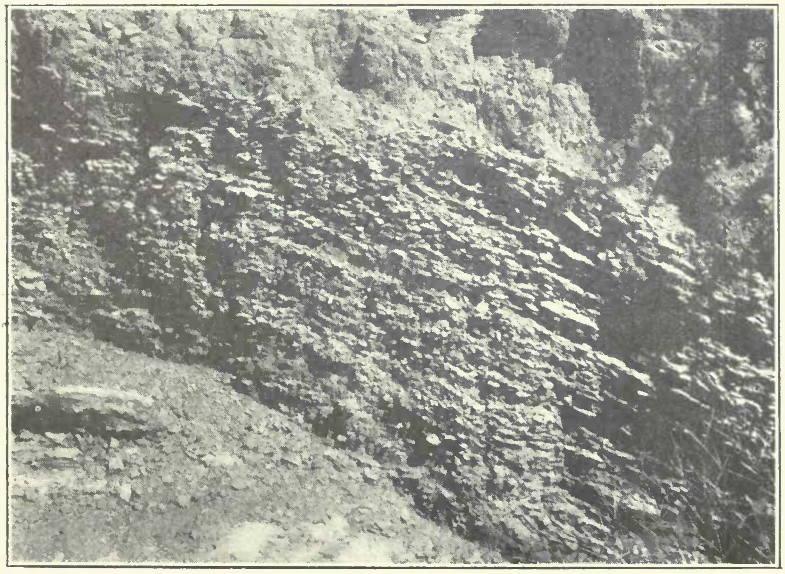

Plate VI.

Arching of phosphate rock beds over underlying limestone. United Phosphate and Chemical Company, near Wallace, Ky.

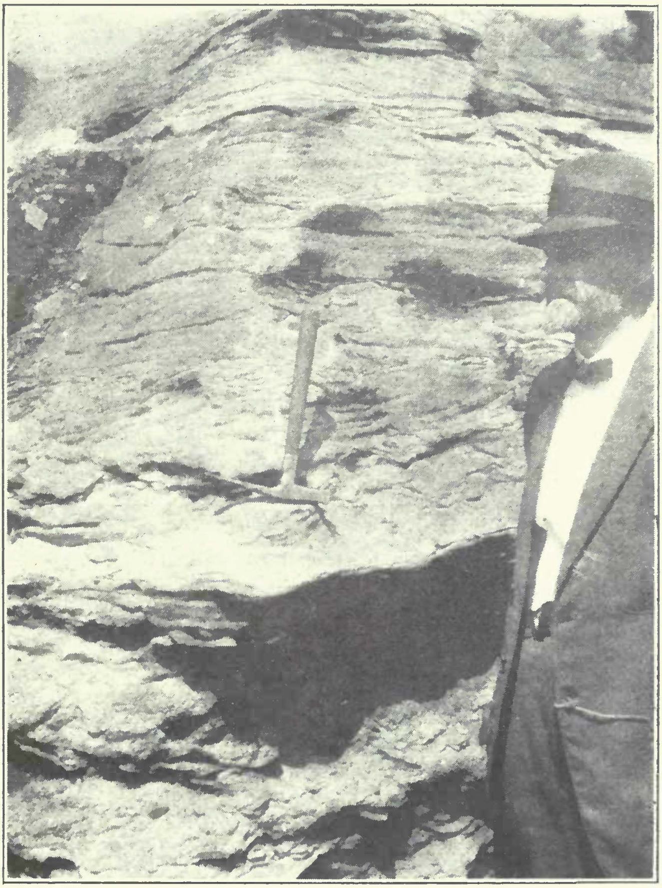

Plate VII.

Limestone with interlaminated phosphatic layers. Type of rock from which phosphate deposits are derived. Quarry on Haggin estate, east of Maysville pike, 7 miles northeast of Lexington, Kentucky.

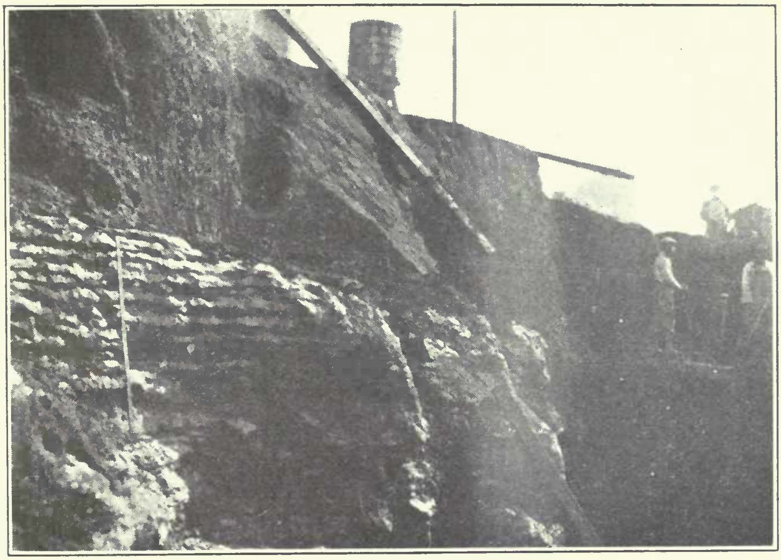

Plate VIII.

Alternating layers of limestone and phosphatic material, Mt. Pleasant, Tenn.

Plate IX.

View in old phosphate workings showing "cutters" and limestone "horses." Near Wallace, Ky.

Plate X.

Arching of phosphate rock over limestone horses. Near Mt. Pleasant, Tenn.

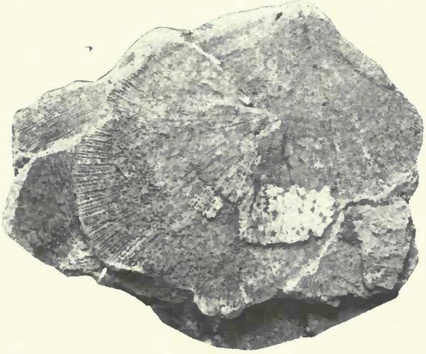

Plate XI.

Rafinesquina alternata from near Versailles, Woodford County, Ky. The shell has been replaced by SiO_2 and $Ca_3(PO_4)_2$ has infiltrated and formed a cast of the interior of the shell.

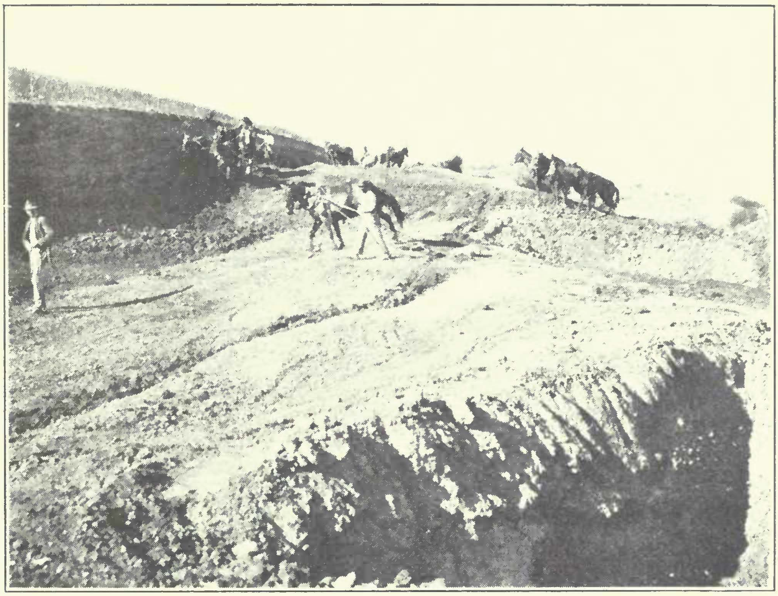

Plate XII.

Removing overburden with scrapers. Near Scotts Mill, Maury County, Tenn.

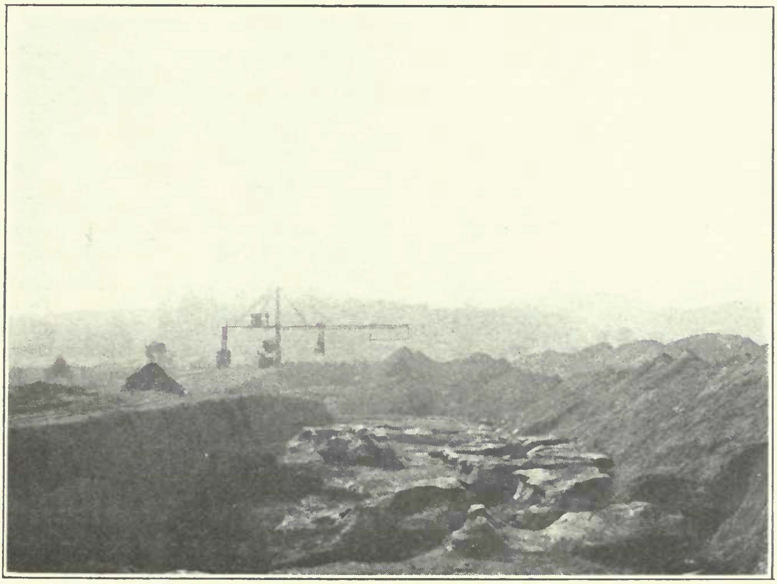

Plate XIII.

Distant view of a cantilever, showing an open pit in part worked out, Mt. Pleasant, Tenn. Note the method of disposing of overburden; limestone horses, cutters, and phosphate rock curving over horses.

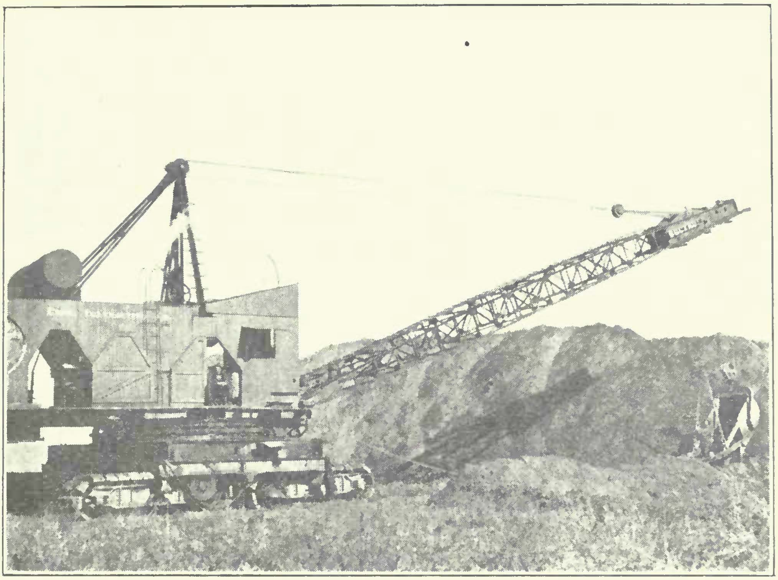

Plate XIV.

A typical drag line excavator at work stripping overburden.
Mt. Pleasant, Tenn.

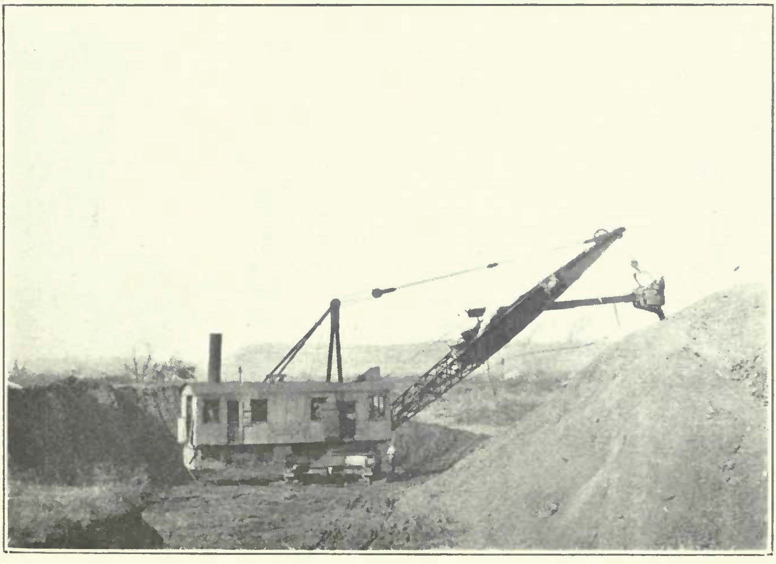

Plate XV.

A steam shovel removing overburden, Mt. Pleasant, Tenn.

Plate XVI.

Mining phosphate rock with hydraulic gun, near Mt. Pleasant, Tenn. Overburden is also removed by this method.

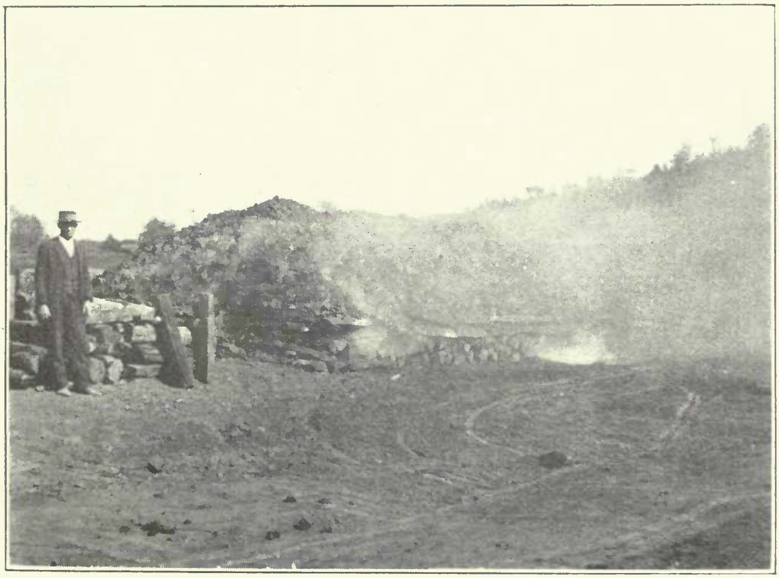

Plate XVII.

Drying phosphate rock by burning in open kilns, Mt. Pleasant, Tenn.

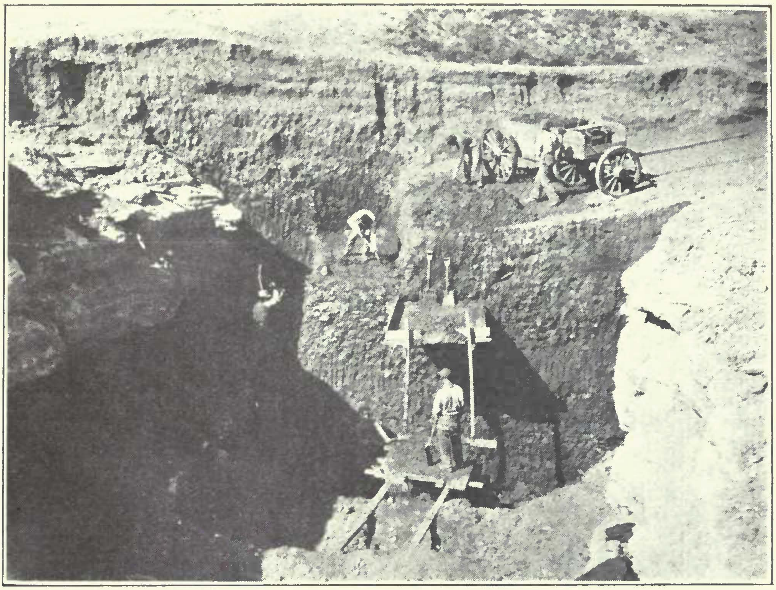

Plate XVIII.

A deep and wide cutter. Shows the method of removing phosphate rock by hand from deep cutters. Mt. Pleasant, Tenn.

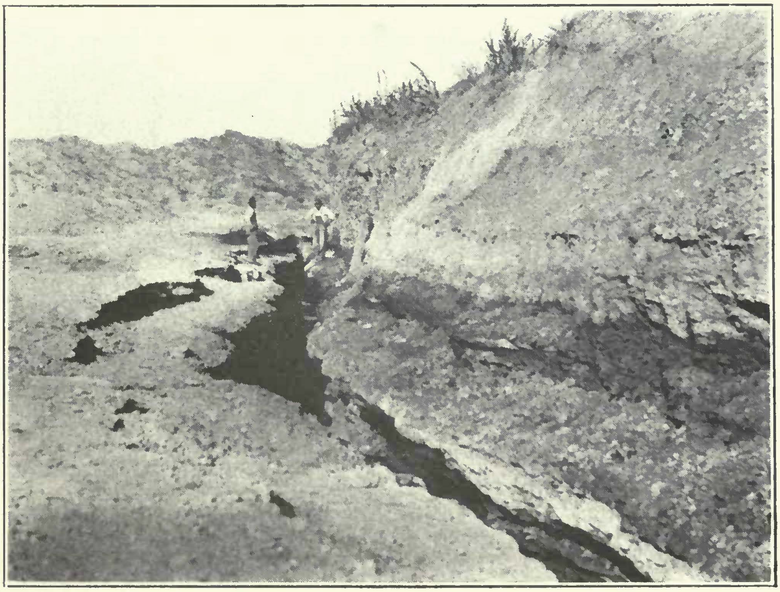

Plate XIX.

A very narrow cutter from which it is difficult to remove the phosphate rock, Mt. Pleasant, Tenn.